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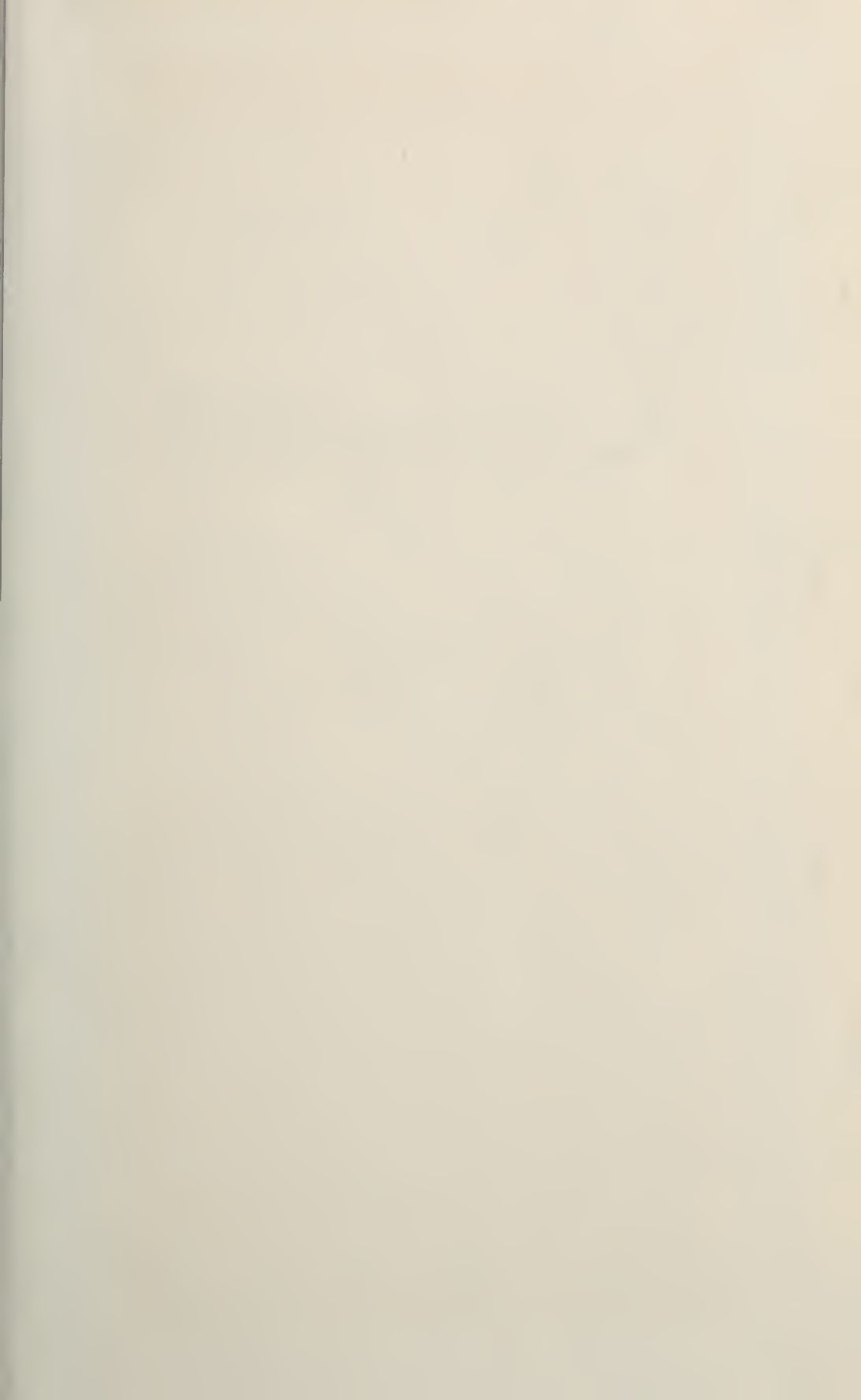
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THE FORM AND FUNCTIONS OF
THE CENTRAL NERVOUS SYSTEM

THE FORM AND FUNCTIONS OF THE CENTRAL NERVOUS SYSTEM

An Introduction to the Study of Nervous Diseases

BY

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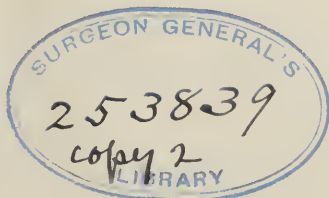
FOREWORD BY

GEORGE S. HUNTINGTON, Sc.D., M.D.

Professor of Anatomy, Columbia University

SECOND EDITION

591 FIGURES CONTAINING 763 ILLUSTRATIONS
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DEDICATED
TO
PROFESSOR GEORGE S. HUNTINGTON

*In grateful recognition
and affectionate appreciation of his teaching and
friendship which have been a
constant guide and an unfailing
inspiration for many
years*

PREFACE TO SECOND EDITION

THE demand for a reprinting of this book has offered the opportunity to correct typographical and other errors usually found in first editions. The short time intervening since its first appearance has permitted of no radical changes in text or illustrations. Many helpful suggestions of those who have been kind enough to criticize the book have been incorporated in this new edition.

NEW YORK CITY,
December, 1922.

F. T.
H. A. R.

PREFACE TO FIRST EDITION

FOR a number of years the authors have had the privilege of teaching neuro-anatomy to medical students in Columbia University, and also, during the war, to many of their medical colleagues assigned by the Surgeon General to the New York Neuro-Surgical School. In teaching; it has been their aim to keep in view the pertinence and value of knowledge concerning the structure of the nervous system in its actual application to clinical medicine. Not the least among the difficulties of presenting such a course is the lack of any satisfactory textbook. No single work provides a clinical and physiological interpretation of the brain and spinal cord adequate to the requirements of practical application.

In so far as possible, the method of illustrating anatomical and physiological facts by clinical examples has been adhered to in this book. The citation of actual cases caused by organic disturbances of the tissues is extensively utilized to elucidate the significance of the several divisions of the brain and spinal cord. By this method the anatomy and physiology of the central nervous system are no longer permitted to remain as independent branches of medical science, but are here incorporated as essential parts of the practical knowledge necessary to the proper diagnosis and treatment of disease.

The need of the student for the most explicit presentation of facts has been recognized in all discussions, although the danger of lapsing into unnecessarily dogmatic statement has not been overlooked.

For the most part, the interpretations given are those which have received the sanction of general acceptance. In a few instances, however, where the limits of our present knowledge concerning the functions of the nervous system are not yet discernible, certain theoretical conjectures have been advanced, both for the purpose of avoiding confusion for the student, and in the hope of stimulating further investigation. There can be no question as to the desirability of such conjectures if for nothing else than that they demonstrate

to what extent the field of Neurology still invites the interests of future workers.

In addition to much original work, many sources have been drawn upon for neurological facts and interpretations. Chief among these have been the great modern masters of Neurology, Cajal and Déjerine. The more recent contributions of distinguished English neurologists, including such leaders as Gaskell, Elliot Smith, Hughlings Jackson, Head, Sherrington, Horsley, Holmes, Campbell and Wilson have provided a wealth of material. We are indebted to the work and influence of the American School of Neurology which has contributed extensively to the elucidation of the Component Theory of the Nervous System. In this connection, we desire especially to mention Professors H. F. Osborn, C. F. W. McClure, O. S. Strong, C. J. Herrick, G. Carl Huber, Adolf Meyer, J. B. Johnston, F. L. Landacre and W. B. Ranson; as well as such noted clinical teachers as Professors M. Allen Starr, C. L. Dana, C. K. Mills, William Browning, C. A. Elsberg, T. H. Weisenburg, Smith Ely Jelliffe and J. Ramsay Hunt.

We also take much pleasure in expressing our sincere gratitude to a number of co-workers whose efforts and assistance have been of greatest value: To Professor F. C. Wood for his supervision and advice in the photomicrography; to Miss Regina Unger for her unsurpassed technical skill in the preparation of histological sections of the brain and spinal cord; to Mr. Ivan Summers for the original drawings; to Miss Alice Goldsmith for her painstaking work on the manuscript and index. It is difficult for us to express adequately our deep sense of appreciation for the courtesy, generosity and cooperation of our publisher, Mr. Paul B. Hoeber and his editorial staff.

October 6, 1920

F. T.
H. A. R.

FOREWORD

A RECENT issue of *Science*¹ records, under "University and Educational News," a significant change in medical educational policy lately introduced at the University of Oregon with the establishment of a new chair whose first incumbent is designated as the "Professor of Zoology and Director of Fundamental Education in Medical Science." In explanation of this action of the medical faculty the reference further states that "an attempt will be made to bring together in one course the premedical and medical years and to obliterate the divisions commonly existing between premedical, preclinical and clinical studies."

This action of the Oregon institution is interesting as an instance of a modern trend in the evolution of medical education which is beginning to make itself felt not only in this country, but also abroad. This movement is in the first place based on a fuller recognition and evaluation of the cardinal fact that morphology, physiology and biochemistry underlie all sound ideals of medical education. Upon the breadth and solidity of this supporting fundamental basis rests the security of the entire superstructure of medical teaching in the clinical branches of the later years, which is constantly expanding into greater complexity and specialization of detail with the steady advance in medical research and technique.

Coupled with this realization, and as its direct result, is a reaction on the part of the teachers in the laboratory branches. While the fundamental biological sciences are accorded their full value as indispensable preparation for the study of the practical side of medicine by clinicians, the teachers of these so-called preclinical branches are in turn beginning to realize the importance of utilizing the three clinical factors of injury, disease and variation as invaluable experimental demonstrations illustrating the significance of the structural, functional and chemical facts with which they primarily are concerned.

¹ Vol. XII, No. 1343, Sept. 24, 1920.

Nowhere in the entire domain of medical education are these facts more clearly accentuated than in the adjustment of those branches of science which are grouped together to constitute the general field of vertebrate neurology. The interlocking facts of development, structure and function, and their interpretation under normal as well as pathological conditions, present an educational territory so complex in its relations and so replete with details as to call for the closest union of all the forces engaged in its cultivation.

This need of cooperative extension becomes most marked in the purely morphological aspect of the entire subject.

No experienced instructor in the anatomy of the central nervous system fails to realize fully the difficulty of adequately presenting the enormously complicated and intricate details of his subject in such form to his students for mental digestion and absorption, and with such collateral aids, as will bring the utmost possible clarity into the discussion and at the same time add a distinct realization of the interdependence of the various disciplines which combine from several sources to supply each a special part of the detailed picture forming the connected whole when brought into its proper position. For the purposes of sound morphological instruction and interpretation the neurological wards of a teaching hospital, its case-histories and other illustrative material constitute for the neural morphologist the only available authoritative laboratory of experimental zoology in which morbid conditions, altering the normal physiological reactions, point to the morphological basis and afford the final and conclusive demonstration of the functional significance underlying the details of organic structure.

The medical curriculum, charged with many crimes of both omission and commission, is perhaps nowhere blamed more justly than in its fatal heterochronic assignment of the correlated and mutually supplemental topics of morphological and clinical neurology to different parts, and mostly to different years, of the course, thus depriving each of the indispensable aid of the other which a synchronous consideration would afford.

These considerations led a number of years ago at Columbia University to the uniting of the structural, functional and clinical

aspects of neurological teaching under the directorship of the senior author of the work now presented.

Based on the Theory of the Neural Components, in the establishment of which American Science has contributed so largely, this book offers its consideration of the vertebrate central nervous organization from the standpoints of Phylogeny, Ontogeny, Morphology, Physiology and Pathology in a thoroughly connected and clear analysis which at all times keeps in open view the ultimate main purpose of this great undertaking, the comprehensive presentation of the cardinal factors involved in their mutual relationship.

The authors sum up the fundamental concept which guided and directed their labors in their "Introduction to the Study of Nervous Diseases" as follows: "This work is designed to fill the gap between morphology and the practical requirements of clinical medicine. It aims to visualize the living nervous system, to make accessible an appreciation of its vital relation to the functions which go to make up life as well as the defects in these relations which result in disease."

How well they have attained the goal thus set at the outset of the undertaking, the admirable result achieved with this publication is destined to show. Its ultimate place in scientific literature may be confided to the judgment of those who will read and study its pages.

The authors, beginning as my students, became my valued colleagues, an association which during the course of many years has grown into a close friendship. They have honored me by asking me to write a foreword to their book. I am conscious of the fact that nothing I have said can add one element of value to the great intrinsic worth of their contribution; but I feel that I cannot resist the expression of my own sense of gratitude for the privilege which I have enjoyed and the mental stimulus I have received in being permitted to observe and profit by the years of intensive and productive study in the morphological laboratory of this institution which have gone into the creation of this volume. As I have constantly profited in mind by this close association during the growth of their work, I rejoice in the fact that the same opportunities will be offered to a far wider circle of students through its pages. I am

confident that they will likewise find their task made lighter, their vision cleared and their mental outlook widened by the broad conception and stimulating presentation which enlivens the pages of this volume.

On behalf of my University I wish to express our grateful appreciation of this product of a ripe American scholarship and training.

GEORGE S. HUNTINGTON.

DEPARTMENT OF ANATOMY,
COLUMBIA UNIVERSITY,
October 8, 1920.

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THE FORM AND FUNCTIONS OF THE CENTRAL NERVOUS SYSTEM

AN INTRODUCTION TO THE STUDY OF NERVOUS DISEASES

CHAPTER I

THE CENTRAL NERVOUS SYSTEM

ITS IMPORTANCE AND SIGNIFICANCE

The Value of the Anatomy of the Nervous System in the Practice of Medicine. The anatomy of the nervous system to many physicians and medical students is reminiscent of struggles with complicated parts of the body which seem to have little practical value. It has an established reputation based upon its difficulties rather than upon the advantages of understanding it. In large measure, this point of view may be ascribed to methods of approach which usually fail to make clear the pertinence of such knowledge. The study of the nervous organs is too often limited to the conditions of *rigor mortis*. It has come to be a citation of many labelled parts without regard to their dynamic significance, an exercise in pure morphology without the accompanying reasons for its importance and application to practice. Yet every phenomenon of human life is to some degree regulated by the nervous system, and there are few diseases which do not manifest defects in its controlling influences.

This work is designed to fill the gap between morphology and the practical requirements of clinical medicine. It aims to visualize the living nervous system, to make accessible an appreciation of its vital relations to the functions which go to make up life, as well as the defects in these relations which result in disease.

The diagnosis of nervous conditions, while in the main of interest to those particularly devoted to the study of neurology, has no little importance to all physicians. It is becoming more generally understood that neurological diagnosis depends primarily upon accurate anatomical knowledge and that without such knowledge many embarrassments may arise. There are no better illustrations of this fact than the common errors made in distinguishing between the functional and organic diseases of the nervous system. The Great War has shown that there is a large number of disorders affecting the organism which may simulate disturbances due to actual or-

ganic lesions. Such, for example, are the cases of "shell-shock," in which a suddenly developing paralysis may have all the appearances of a disease in the brain, in the spinal cord or in the peripheral nerves, and yet, when tested by anatomical rules, will prove themselves to be of another category altogether.

Without knowledge of anatomy and physiology, it would be impossible to locate the position of many lesions which might be accessible to surgical interference. The signs which point to the anatomical level of injuries of the spinal cord, to involvement of the cerebellum, to affection of the occipital, parietal, temporal, frontal and prefrontal areas of the brain, serve as



FIG. 1.—A case diagnosed as a spinal cord lesion, which proved to be hysteria and was completely cured by psychotherapy.

guides to localization within the nervous system. How invaluable, for instance, is the information that a patient is suffering from a *bitemporal hemianopsia*, a sign which almost invariably indicates the position of a lesion pressing upon the optic chiasm and in all probability having its origin in the pituitary body. The clinical value of such signs as aphasia, mind-deafness, mind-blindness, and the lack of the proper ability to recognize objects by palpation, emphasizes the necessity of a clear understanding of the anatomy of the brain. Equipped with such knowledge, the surgeon may with accuracy approach the seat of the trouble producing the disturbance in the patient.

Neurology and the Practice of Medicine. It is a general belief that the prac-

ticing physician need know but little of the nervous system. On the other hand, it has been estimated that from fifty to seventy per cent of the physician's work is concerned with diseases of the nervous system. This statement does not seem an exaggeration when one considers the large number of cases coming into the clinical experience of every practitioner which represent that extensive group of disorders classed as the *Neuroses*. Here are found many varieties of disturbances based upon no organic change, but which to each patient are real and often dominant factors in his life. Every organ and system in the body has its well-recognized series of functional nervous diseases, the treatment of which requires skill and judgment. But before treatment

may be applied to such disorders, it must be determined that they are in fact functional diseases. To make this decision requires the ability to distinguish between affections having no organic basis and those due to some actual tissue change. The frequency with which this differentiation fails to be made is well recognized. It is not an uncommon experience to find a case with some grave organic change receiving treatment under the diagnosis of neurasthenia, hysteria or a neurosis.

There is a broader view, however, in the light of which the physician should be versed in the anatomy of the human body. Since disease may be regarded as a deviation from the normal processes of life, a clear conception of these processes becomes fundamental. This presumes a knowledge of all the organs, of their individual as well as their integrative significance, and of the means by which they are brought into and maintained in cooperation.

It is not difficult to appreciate the necessity of understanding the normal workings of a mechanical device before we undertake its repair; yet it cannot be said that we have provided ourselves with such a full understanding of the human mechanism before we attempt the treatment of its disorders. In the main, we have made disease our chief interest. As a matter of fact, life is the principal theme, to which disease is but a corollary. The purely pragmatic attitude toward medicine is not without its defects. It fails to encourage



FIG. 2.—A case diagnosed as hysteria, which upon further examination proved to be a case of epidemic encephalitis.

an approach to the salient problems concerning the significance of life; it omits, as theoretical, the considerations of development and adaptation. Although it lends facility to professional administration, it does not establish the philosophical attitude upon which the advance as well as the practice of medicine ultimately depend.

The Evolutional Significance of the Central Nervous System. The human body is the consummation of a record made through inestimable periods of time by adaptive modifications in the organic materials constituting life. The nervous system is rich in the record of these modifications; it probably

holds the entire transcription of the changes which have occurred during the evolutionary period. It is possible to find evidence for much of this at present, and much remains to be revealed. Not alone in the human body is this evidence to be sought; a vast amount of it will be found in the lower forms of animal life and in the embryological development of the species. Such evi-



FIG. 3.—A case diagnosed as hysteria, which upon autopsy proved to be a case of Wilson's disease, progressive lenticular degeneration.

dence cannot fail to make more clear our insight into the relations of the nervous system to the body as a whole. Comparative anatomy and embryology will be, in this sense, valuable aids to our interpretation, and will furnish numerous clues to the meaning of parts which otherwise could be scarcely more than structures requiring identification.

The Centralization of the Nervous System. Concerning the nervous system, it may properly be asked, What are its functions, and how does it serve the living animal? In stating this question, we should bear in mind that our inquiry deals with the generalized plan according to which any vertebrate animal is enabled to carry on the process of sustaining life. One striking feature about this process of living is that it results from a cooperation of many different structures; in fact, all parts of the body must act harmoniously if health and life are to be preserved. It is

often the case that organs which participate in this action are situated at relatively great distances from each other, yet their activity must be synchronized in the rate and rhythm of their operation as well as in the quantity and degree of their action. Such cooperation as this could not be left to chance; and so it has come about that its regulation has been centralized in a set of organs known as the nervous system.

In general, the animal lives through the operation of two major mechanisms, one of which keeps it in contact with its environment, while the other controls its vital processes.

THE TWO MAJOR MECHANISMS CONTROLLED BY THE NERVOUS SYSTEM

Somatic Mechanism. The first of these two mechanisms, that which keeps the animal in contact with its environment, concerns itself in the strict sense with the management of the body. It is, so to speak, an externalizing mechanism. All of the movements of the limbs, the trunk and the head, which may be employed consciously or non-consciously for the purposes of the animal's welfare, are produced and regulated by this mechanism. It serves the requirements of obtaining food, of regulating that behavior without which starvation would ensue; it controls those reactions by means of which protection against inimical factors is provided, either through defensive or offensive acts; it furnishes all the complicated performances by which the animal is able to hold its allotted position as an individual and, in perpetuity, as a species. It is unquestionably true that this mechanism has afforded one of the chief means by which adaptation has been made to new environment, and has thus laid the foundations for progression in the process of evolution. Because of its participation in these bodily activities, it is known as the *somatic mechanism*.

Splanchnic Mechanism. The second of the essential mechanisms has to do with the more intimate and vital activities of living, such, for example, as the circulation and respiration, digestion and elimination. Through its operation are administered the processes of absorption of essential nutritive material, of the chemical and physical treatment of such substances, of their proper assimilation and their distribution to the destinations in the body where they are employed as sustenance of life or transformed into vital energy. In this category also belong those functions whose main office it is to eliminate unnecessary substances which accumulate in the body as a result of the many chemical changes constantly going on. Because this has to do with the visceral functions, it is known as the *visceral* or *splanchnic mechanism*.

The harmonious interaction of these two mechanisms is essential; should it fail, it is not difficult to conceive what disturbances might ensue. If, for example, when the whole organism is in need of nutrition, the somatic mechanism ceased to operate and the animal did not perform those acts necessary for obtaining food, it is easy to foresee what disaster would overtake the vital processes. Such examples may be multiplied indefinitely; but they all go to show the necessity of synchronism between the parts which have to do with somatic activities and those which regulate splanchnic functions. Their intimate interrelation is graphically illustrated in the conception that *the somatic mechanism regulates the efforts of life, while the splanchnic mechanism controls the essence of life*.

Components of the Nervous System Controlling the Two Major Mechanisms. Each of these mechanisms comes under the control of two principal divisions or components in the nervous system. One of these is represented by an extensive series of highly sensitized organs called *receptors*, which are capable not only of detecting changes in or about the body but also of rapidly transmitting the impression of these changes to definite stations where they may be registered and properly utilized. The receptor and the transmitting mechanism constitute the *afferent* or *sensory component*.

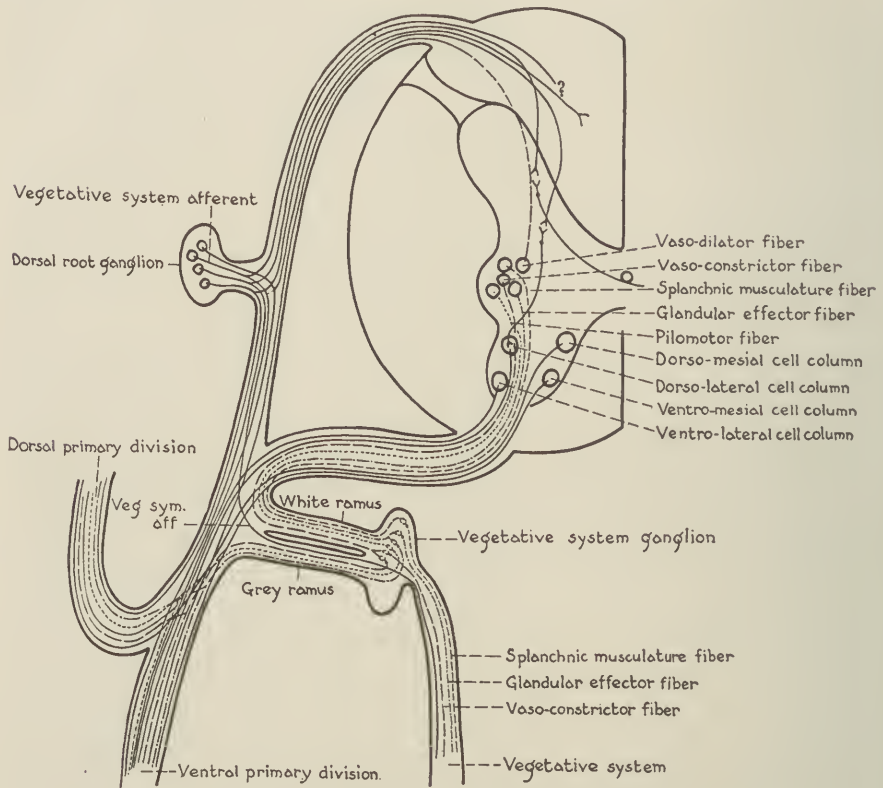


FIG. 4.—The somatic and splanchnic components of the nervous system.

The second principal division controlling each mechanism is represented by an equally extensive series of organs called *effectors*, in which the response takes place, such as muscular contraction or the secretion of a fluid. The elements activating the effectors, together with the effectors, constitute the *effluent* or *motor component*. It will be seen that, taken together, there are four components in the somatic and splanchnic mechanisms; these are:

1. The Somatic Sensory or Afferent Component. (See Glossary.)
2. The Somatic Motor or Efferent Component.
3. The Splanchnic Sensory or Afferent Component.
4. The Splanchnic Motor or Efferent Component.

Each of these components occupies a definite territory in the spinal cord

and brain, which constitutes its central portion. By means of afferent and efferent nerve fibers, which form its peripheral portion, it receives impressions from and despatches impulses to the structures under its control. In this light, the nervous system may be regarded as a structure performing its functions through the cooperation of four coordinate departments. It is not difficult to realize the manner in which such departmental organization contributes to the operating advantage of the entire organism. This conception is known as the *component theory of the nervous system*.

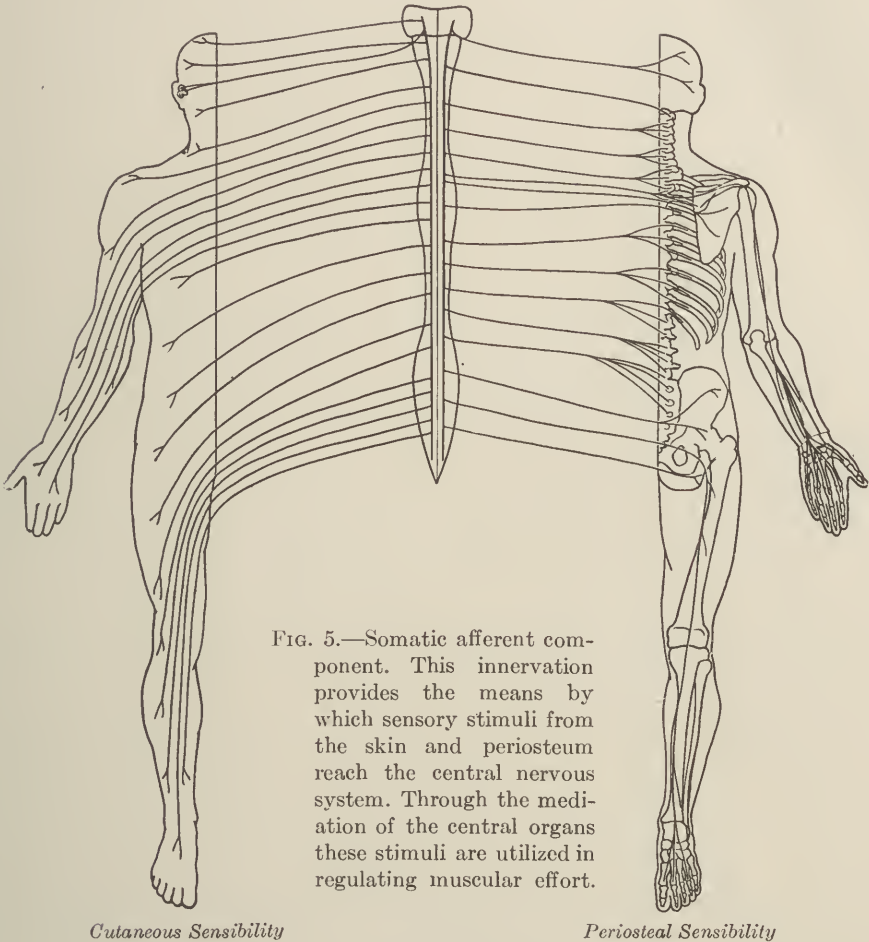


FIG. 5.—Somatic afferent component. This innervation provides the means by which sensory stimuli from the skin and periosteum reach the central nervous system. Through the mediation of the central organs these stimuli are utilized in regulating muscular effort.

Cutaneous Sensibility

Periosteal Sensibility

1. *The Somatic Sensory or Afferent Component.* This component furnishes the means of sensory intake from the entire surface of the body as well as from all of the skeletal structures. It is the great avenue by which all information from the outside world is received. Such information comes primarily to the somatic sensory receptors in the form of various stimuli. These receptors are represented by various end-organs located near the surface of the body. Organs of this kind are found in the skin and

its appendages. The purpose of these stimuli is to create touch or tactile impressions which give rise to a type of sensation known as *tactile sensibility* (*thigmesthesia* [*thigma*, touch; *esthesia*, feeling]). The importance of such sensibility is apparent. It is only necessary to observe the actions of a patient who has lost tactile sense in the hands to appreciate the serious limitations in activity which this loss imposes. In addition to the epidermal surface of the skin, certain appendages, particularly the hairs, are important accessories for receiving surface stimuli.

Another set of organs is especially designed to convey information concerning the temperature of the environment, whether it be the temperature of the air which surrounds the body or the fluid medium in which the animal lives. The tissues are adapted to a certain limited range of temperature, extremes above or below which are deleterious. To avoid destruction from such temperatures, the body is provided with organs which detect thermic changes. In addition to this primitive function of thermal sensibility, the ability to distinguish between degrees of heat and cold has furnished a valuable means of sensory differentiation. Temperature sense is known as *thermal sensibility* (*thermesthesia*).

It is not alone from the surfaces of the body that stimuli reach the nervous system. In order that muscles may be equipped in such a way as to convey sensory impressions concerning their contractile status, their state of relaxation or tension, definite sensory organs are found among the muscle bundles. These are connected with nerve fibers and thus with the spinal cord and brain-stem. The significance of such a pathway from the muscles is apparent, since by this means the individual acquires muscular awareness. If the avenues of this deep sensibility are interrupted, muscle sense is lost and it is no longer possible to direct corrective impulses in the adjustment of muscular acts. The results of such a disturbance are frequently seen in *locomotor ataxia*, a common nervous disease in which the patient is no longer able to evaluate the character of his muscular movements and manifests in them an inaccuracy described as *ataxia*.

The bones, the joints and the fasciæ also have sensory organs which convey to the central nervous system impressions of much value in estimating the location and relations of the limbs and of the several parts of each limb, one to the other. Special sense organs located in the periosteum of the bones respond to stimuli giving information concerning the character of the surface upon which the individual happens to be standing or resting. Collectively, this is known as *deep sensibility* (*bathesthesia*). The special impressions coming from the muscles give rise to *muscle sensibility* (*myesthesia*), those from the joints to *joint sensibility* (*arthresthesia*). The bones, and the periosteum covering them, are provided with organs responsive to stimuli which determine *vibratory sensibility* (*pallesthesia*).

An important set of sensory organs giving information with reference to the spatial relations of the body are the *semicircular canals*. These are minute, tubular structures in connection with the ear, so placed as to correspond to the three planes of space. They are filled with a fluid, changes in

which produce stimuli that are transmitted to the central nervous system and utilized in readjustments necessary in maintaining the balance of the body. This is known as *balance sensibility*.

In addition to the stimuli which gain access to the body through contact with its surface or originate in its skeletal structures, there are others which arise at a distance and are conveyed through the intervention of some medium, either air or water. The chief purpose of these stimuli is to direct the

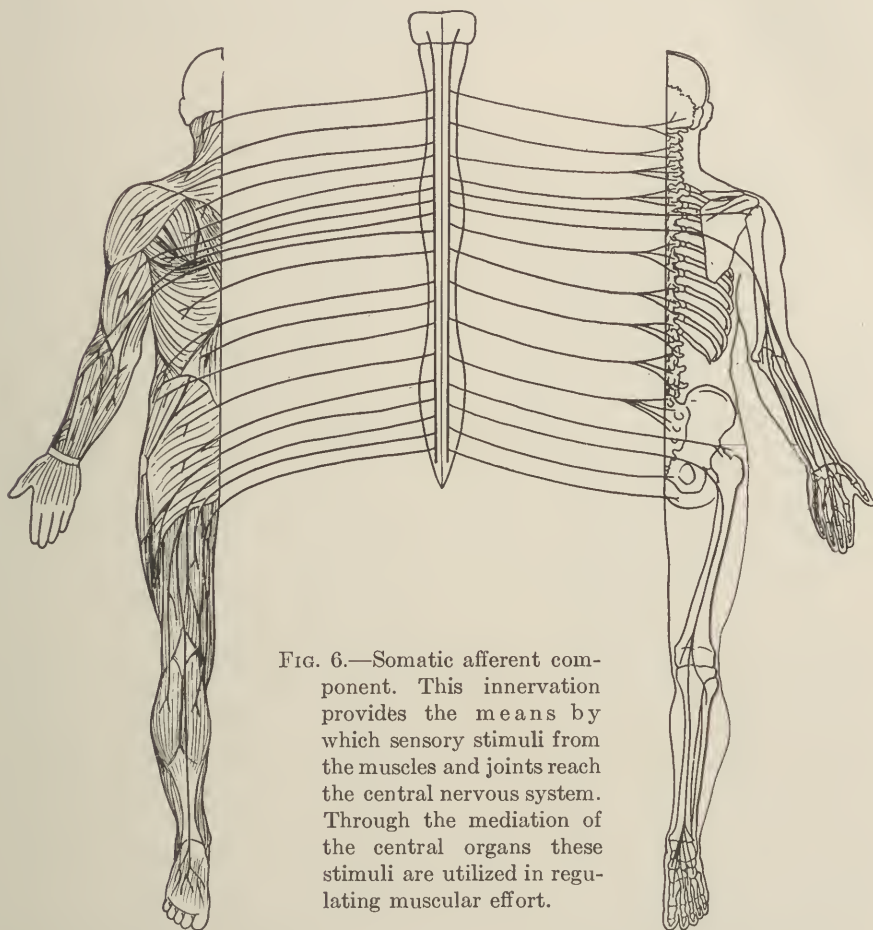


FIG. 6.—Somatic afferent component. This innervation provides the means by which sensory stimuli from the muscles and joints reach the central nervous system. Through the mediation of the central organs these stimuli are utilized in regulating muscular effort.

Muscle Sensibility (Myesthesia)

Joint Sensibility (Arthresthesia)

somatic actions with reference to objects outside of the body which the animal purposes to approach or avoid. The most primitive of these distance stimuli are those affecting the sense of smell, for which a special apparatus has come into existence. The impression arising from this type of sensory stimuli constitutes *olfactory sensibility (osmesthesia)*. No less important are the distance stimuli which reach the central nervous system by means of the visual apparatus, giving rise to *visual sensibility (optesthesia)*. A third somatic sensory

apparatus receiving stimuli from a distance is the auditory mechanism, through the agency of which is produced *acoustic sensibility* (*acuesthesia*).

The specialized types of apparatus designed to receive stimuli from a distance are usually referred to as the organs of *special sense*. In a general way, this is a useful distinction; but on the other hand, each quality of sensibility is represented by a special sense of its own. The specialty of smell, hearing and vision depends not upon a difference in kind but rather upon a difference in the degree of specialization in the end-organs of these senses. As will be seen later, the organ for the reception of tactile stimuli is highly specialized, although it does not approach the extreme morphological differentiation exhibited by the eye.

All the structures designed to receive and transmit sensory stimuli from the surface and skeletal parts of the body constitute the *somatic afferent or sensory component*. One special feature concerning this component is variously interpreted by different authorities. Each of the several sense-qualities, including touch sense, temperature sense, deep sense and the distance senses, is capable under certain circumstances of giving rise to sensations quite at variance with that for which it usually serves. Thus, tactile stimuli may, under certain conditions, convey impressions to the brain which, in addition to the fundamental touch perception, provoke a sensation of discomfort, distress or pain. It would seem that when the stimulus transcends the threshold of mere touch feeling, it tends to reach a level at which it causes actual pain. The significance of this becomes clear when we consider that such stimuli are usually harmful to the tissues. In this manner tactile sense is equipped with an unusual pathway by which impressions unusual in their severity may communicate the nature of their stimulation to the central nervous system which, in turn, responds by an adequate defense reaction. This same accessory protective apparatus is found running parallel with the course of every quality of sensibility. The usual and proper stimuli in each sense-quality pass by means of a customary pathway; but when these impressions become excessive and pain results, be it in the sphere of any type of sensation, touch, temperature or muscle sense, then some part of the body is threatened by unfavorable circumstances, and the excessive stimuli follow a special pathway to communicate this information to the central nervous system. This sensory element, forming the basis of a general protective mechanism, is known as *pain sensibility* (*algesthesia*).

2. *The Somatic Motor or Efferent Component.* It would be to little purpose if all the vast amount of information collected by the human body were not in some way utilized. This information has its real value because of the reactions which it determines and guides. In response to sensory impressions, the body carries out all its innumerable efforts at adjustment. There is no movement, no act, no course of behavior which is not initiated, executed or directed by the influence of body sensibility, so that these sensory influences are actually turned to definite account and made manifest as motion or secretion. For the most part, this type of motion is developed by the *skeletal or striped muscles*. These muscles are peculiar in that they are

subject to the will, and also in that the greater part of their activity is employed in the accomplishment of definite purposes. They are further peculiar because they may be subject to relatively long periods of inactivity during which no actual motofacient contraction occurs. All of the muscles operating in this way constitute the *somatic muscles*, and the portion of the nervous system allotted to their regulation is known as the *somatic motor or efferent component*.

3. *The Splanchnic Sensory or Afferent Component.* This component of the nervous system has to do with the receipt and transmission of sensory impulses arising in the viscera. Although these impressions do not always enter vividly into consciousness, they are none the less important in initiating the glandular activities and smooth muscle contractions whose operations are necessary to the vegetative life. While for the most part the impressions received from the splanchnic sensory areas remain non-conscious, it is nevertheless apparent that there does exist an actual pathway from these areas into our conscious fields. This is illustrated in the sense of relief experienced upon the evacuation of the bladder or rectum. On the other hand, there may be a line of conduction, like the pathway for excessive somatic sensory impressions, less commonly traversed than that followed by the great majority of stimuli travelling inward, when the splanchnic sensory impulses transcend their usual, non-conscious level and become disagreeable or painful. This latter is an equipment making provision for a defense mechanism under circumstances which threaten or actually injure the tissues of the viscera.

4. *The Splanchnic Motor or Efferent Component.* The fourth component in the nervous system is that which directly controls the glands, cardiac and smooth muscles of the body. These, as has already been shown, perform their reactions in response to afferent impulses received through the splanchnic sensory component.

The Cooperation of the Four Components of the Nervous System. Through the four components of the nervous system already described, the activities of life are regulated and controlled. Impressions received

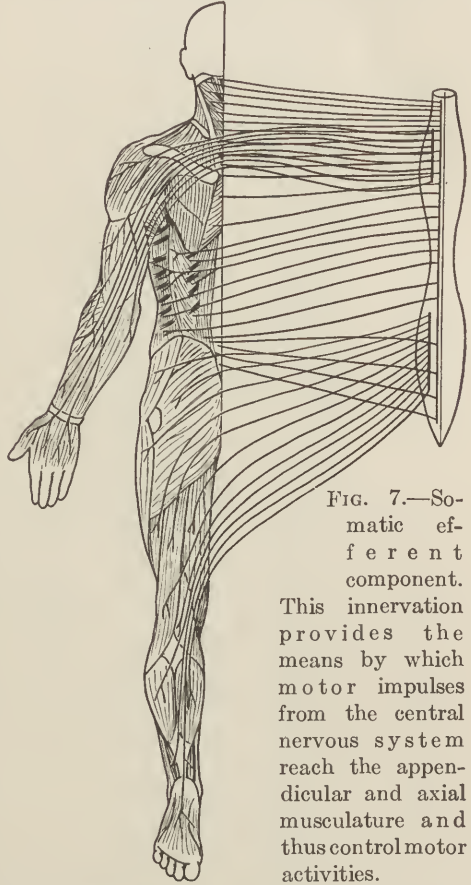


FIG. 7.—Somatic efferent component.

This innervation provides the means by which motor impulses from the central nervous system reach the appendicular and axial musculature and thus control motor activities.

by means of the sensory components are neither transitory nor evanescent, for each impulse leaves a lasting imprint on the nervous system. From the collected mass of these impressions grow the complex processes of sensory association which give rise to memory and at length develop the psychic combinations of individual experience. The apparently intrinsic, psychical operations of the brain may appear to be independent of the four components,

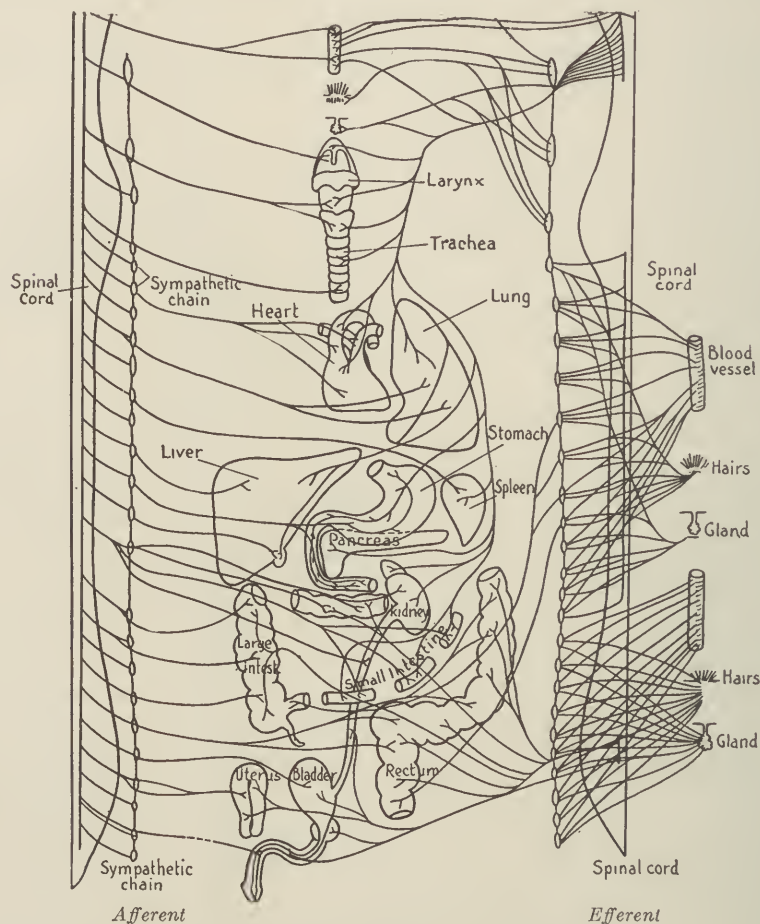


FIG. 8.—The splanchnic components.

Afferent.—This innervation provides the means by which the sensory stimuli reach the central nervous system.

Efferent.—This innervation provides the means by which the motor impulses are distributed to the involuntary musculature regulating the vital processes.

yet none of these higher syntheses would be possible without the fundamental activities of the components themselves. In this light, the psychic life reveals itself as an elaboration of the synthetic interreaction of the components controlling the somatic and splanchnic mechanisms.

Divisions of the Nervous System. For purposes of study, certain divisions of the nervous system may with advantage be made:

First, the *cerebrospinal axis* or *neuraxis*, which consists of the spinal cord and the brain. This portion of the nervous system is centrally placed in the body, the spinal cord occupying the vertebral canal and having its cephalic limit at the margin of the *foramen magnum*, while the brain comprises the portion of the central nervous system within the skull.

Second, the *somatic peripheral nervous system*, which consists of the cranial and spinal nerves, by means of which impulses are transmitted from the surface of the body to the central nervous system and distributed from these organs to the muscles and the glands.

Third, the *vegetative* or *sympathetic nervous system* which forms the connecting link between the viscera and the central nervous system.

It will be seen later that these major divisions are susceptible of subdivision into parts which will require separate description. In order that this study may be comprehensive and practical, each part will be discussed under the following headings:

1. General evolutionary significance.
2. Anatomy, embryology and histology.
3. Physiological significance.
4. Principal syndromes illustrative of anatomical localization and functional significance.

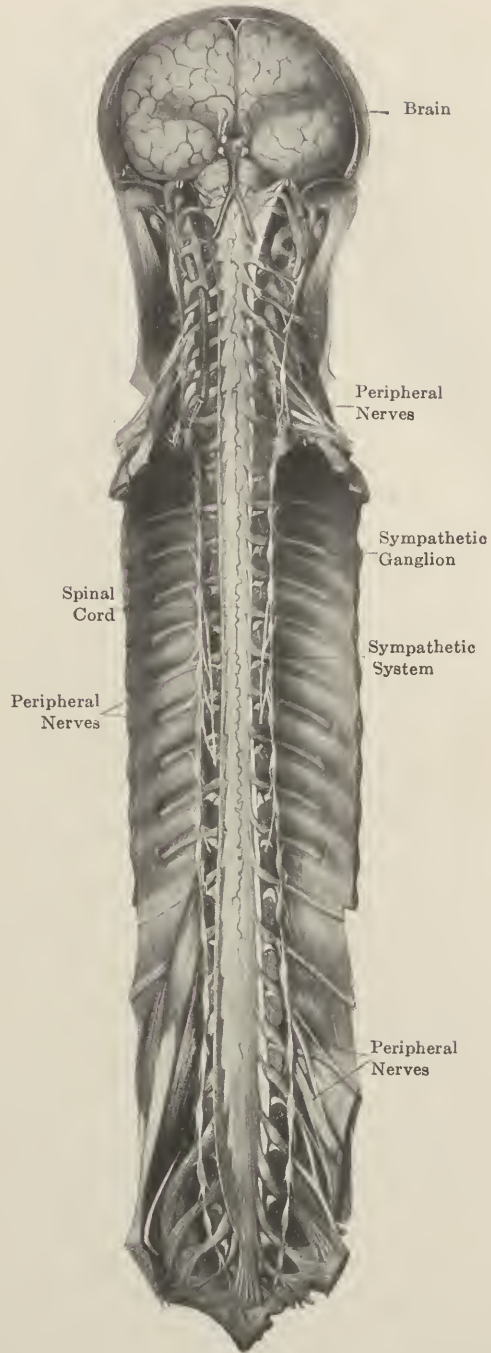


FIG. 9.—Divisions of the nervous system including the cerebrospinal axis, the peripheral nerves and sympathetic system. (Bourguery)

CHAPTER II

THE EMBRYOLOGICAL DEVELOPMENT OF THE CENTRAL NERVOUS SYSTEM

Principle of Development in the Mammalian Embryo. The divisions of the nervous system are most easily understood in the light of their embryology. The description given here follows the general lines of development without giving reference to the finer details which will subsequently be discussed in considering each division of the neuraxis.

In order to obtain material which would show the series of steps from the beginning of this developmental process, it was necessary to select some form other than the human embryo, since satisfactory specimens, especially in the early stages, are difficult to obtain. In consequence a mammalian embryo, *felis domestica*, which may be easily procured, was chosen for this study.

The principle of development in vertebrates depends upon the evolution of two long tubes lying in the longitudinal axis of the body. One of these tubes occupies a dorsal position and becomes the *neuraxis* or *cerebrospinal system*. The second tube is ventral in its position and gives rise to the *gut tract*. At first these tubes are parallel with each other, extending in this relation from the head to the tail-end of the embryo. At an early period a third element grows between them, from which the supporting and motor structures of the body develop. This is the *mesoderm*.

It is to the more dorsal of the two tubes that we must direct attention, since from it the brain and spinal cord take origin. This tube is derived from the outermost layer of the embryo, the *ectoderm*. In the early cleavage stages, when the cells which form the ectoderm are first arranging themselves upon the outer surface of the spherical body of the blastoderm, there are no signs of differentiation which indicate a tendency toward the formation of organs. All of the ectodermal cells appear to have the same general character and arrangement. Presently, however, there appears a faint streak on the outer surface of the spherical vesicle, which marks the general position and direction of the longitudinal axis of the embryo.

THE FORMATION OF THE NEURAL PLATE AND GROOVE

Almost immediately after the appearance of the *primitive streak*, the cells of the ectoderm about it take on new activity and marked local changes become apparent. The ectodermal cells on either side of the long axis of the embryo begin to proliferate rapidly, until they form a relatively thick longitudinal plate which extends outward for a short distance upon either side of

the long axis of the embryo. At its lateral boundaries, the cells of the ectoderm still manifest their primitive arrangement. This central thickened area is the *neural plate*. A faint longitudinal furrow appears near its center at an early stage. This is the *neural groove*. The concentration of cells occupying a central position in the embryo is thus divided into two symmetrically bilateral halves, one of which lies on either side of the neural groove.

THE STAGE OF TWO SOMITES OR THE STAGE OF THE NEURAL PLATE

This stage is observed in the embryo when the first two body segments have developed. The neural plate is somewhat heavier and more prominent at the cephalic extremity, and the neural groove is correspondingly deeper here than toward the caudal end. The plate at the cephalic pole of the embryo has become elevated on either side of the groove to form the *neural folds*. At the edges of the neural plate a faint elevation marks the *neuro-somatic junction*, which is significant

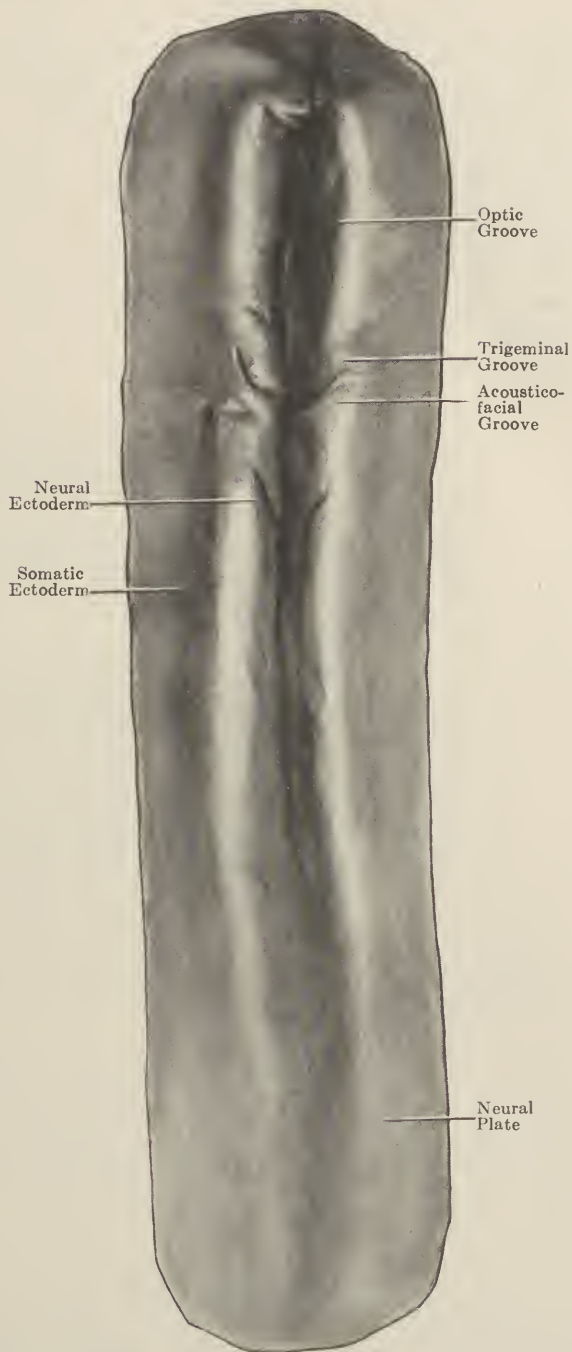


FIG. 10.—Reconstruction of the stage of two somites in the development of the neuraxis; showing the formation of the neural plate. (Schulte and Tilney.)

because it delimits the ectodermal cells destined to form the outer covering of the body from those giving rise to the cerebrospinal axis.

Appearance of the Optic, Trigeminal and Acoustico-Facial Grooves. In the stage of two somites, the embryo shows two fairly well-marked grooves running obliquely from within outward and backward near the cephalic extremity of either neural fold. These oblique grooves are symmetrical in their position, in their form and in the depth to which they indent the neural folds. They mark the beginning of two evaginations which subsequently protrude upon the lateral aspect of each fold near its cephalic extremity. Somewhat further caudally, along the crest of either neural fold, a second pair of grooves makes its appearance. These grooves also extend obliquely from within outward, and although they are not as conspicuous as the first set, they are promi-

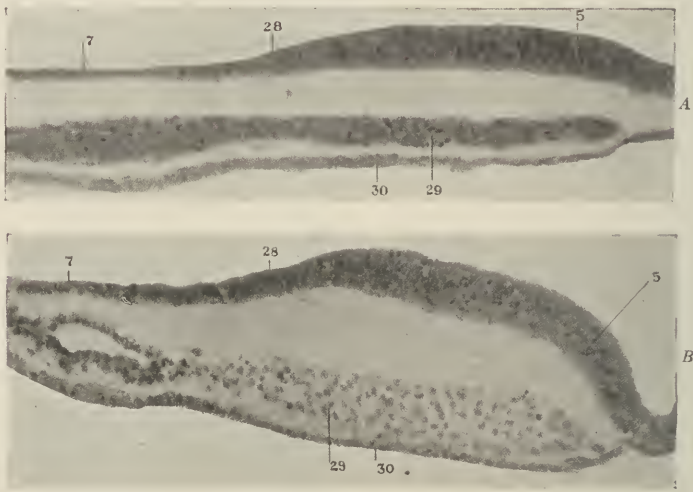


FIG. 11.—Sections of embryos before and after segmentation. (Schulte and Tilney.)

A. Transverse section of an embryo prior to the appearance of intersomitic clefts. 5. Medullary plate 7. Somatic ectoderm. 28. Region of transition. 29. Mesoderm. 30. Entoderm.

B. Transverse section of an embryo at one somite. 5. Medullary plate. 7. Somatic ectoderm. 28. Region of transition. 29. Mesoderm. 30. Entoderm.

nent features at this stage of development. A third pair of grooves develops upon the summit of the neural fold at a considerable distance caudal to the second set. These three sets of grooves should be identified for further reference.

The first set forms the *optic grooves*; the second, the *trigeminal grooves*; and the third, the *acoustico-facial grooves*.

THE STAGE OF FOUR SOMITES

Elevation of the Neural Folds. The embryo of four somites shows a pronounced advance in neural development. The neural folds extend the entire length of the embryo from the cephalic to the caudal extremity. They are not, however, of the same height in all places. In their cephalic portion they have reached their greatest elevation and are approximately perpen-

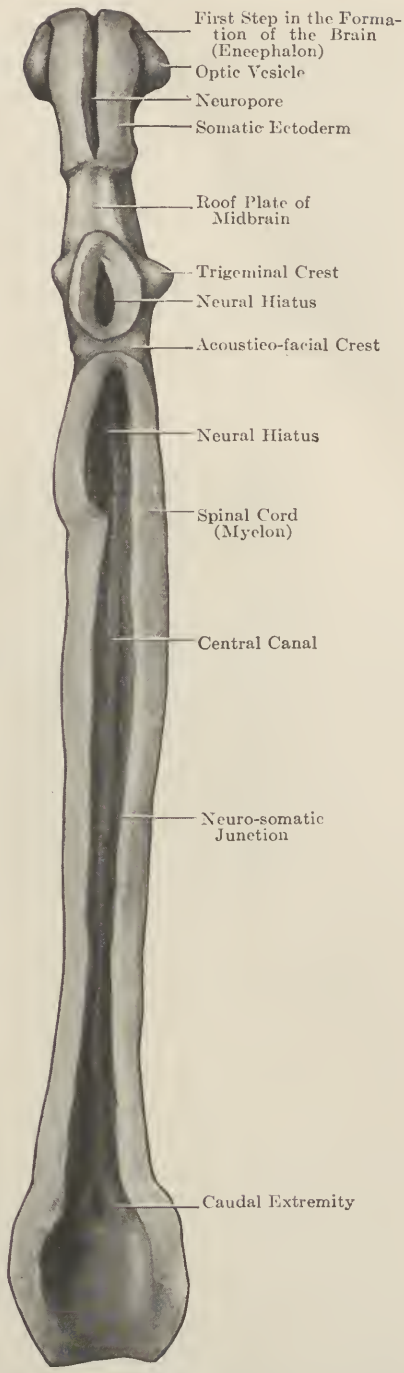
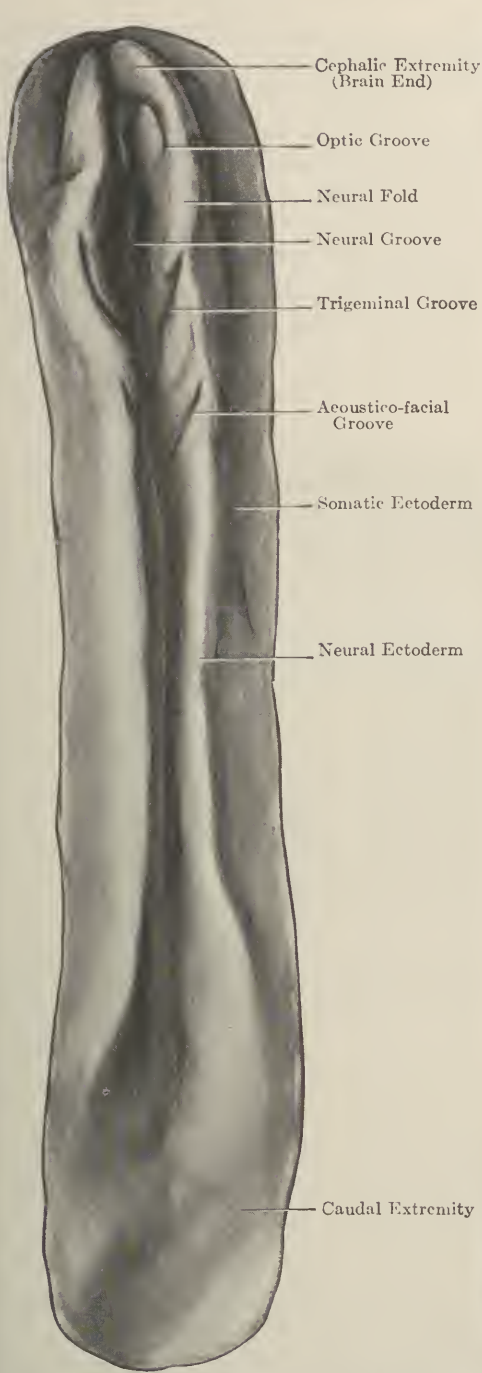


FIG. 12.—Reconstruction of the stage of four somites showing the elevation of the neural folds and the development of the neural groove. (*Schulte and Tilney.*)

FIG. 13.—Reconstruction of the stage of eight somites showing the formation of the neural tube. (*Schulte and Tilney.*)

dicular in position. This condition obtains throughout the cephalic one-third of the folds, but thereafter toward the tail, there is a gradual decrease in their height, while the walls formed by them are less perpendicular. In the extreme caudal areas the folds show little elevation and the neural groove expands to form a semicircular depression. This pronounced change is the result of a gradual rising in each fold until what was previously its dorsal surface now faces inward toward the corresponding surface of the opposite side. As the cephalic borders of the two folds are not yet in contact, there is a cleft between them. The process which results in this elevation of the neural folds ultimately brings the two halves of the neural plate into more intimate relation with each other. A connection between the two lateral walls already exists and forms the *floor-plate*. The walls of the neural folds have

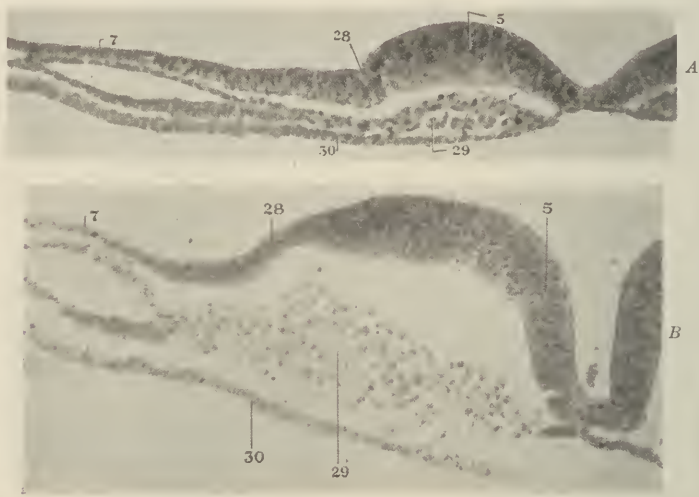


FIG. 14.—Sections of embryos of two and three somites. (*Schulte and Tilney.*)

A. Transverse section of an embryo of two somites. 5, Medullary plate. 7, Somatic ectoderm. 28, Region of transition showing presence of a shallow furrow. 29, Mesoderm. 30, Entoderm.

B. Transverse section of an embryo of three somites. 5, Medullary plate. 7, Somatic ectoderm. 28, Region of transition. 29, Mesoderm. 30, Entoderm.

grown greatly in thickness. In the earlier stage, the neural plate in its thickest region was comprised of four or five layers of cells. Now the neural folds, particularly in the cephalic region, consist of ten to twelve layers of cells. More caudally, however, the thickness of the walls varies from six to eight cells. The innermost layer bordering upon the neural groove is in a state of active proliferation. Numerous karyokinetic figures are observed and rapid cell division is in process. As the new cells form, they move away from the central groove into a more lateral position in the wall. The only elements entering into the formation of the folds, however, are ectodermal cells, the mass of whose deeply staining bodies constitutes the most conspicuous feature in the cross section of the embryo at this stage. There is no evidence of blood vessels or vascular development at this time, so that the nutrition of the relatively dense mass of the neural folds must be provided by special means.

The Neural and Somatic Ectoderm. The relation of the somatic and neural ectoderm has assumed a new significance. The neuro-somatic junction upon the left has been drawn into closer relation to the corresponding junction upon the right, in preparation for the final closure of the somatic ectoderm across the dorsal surface of the neuraxis. The junction itself is indicated at this period by a sharp angle along the line of transition between the neural and somatic ectoderm. This transition is marked by a pronounced change in cellular characters. The somatic ectoderm is composed of two or three layers of epithelial cells, while the neural ectoderm consists of a dense stratified mass constituting the neural fold.

Changes in the Mesoderm. The cells of this intermediate layer between ectoderm and entoderm have proliferated rapidly and now form a mass of

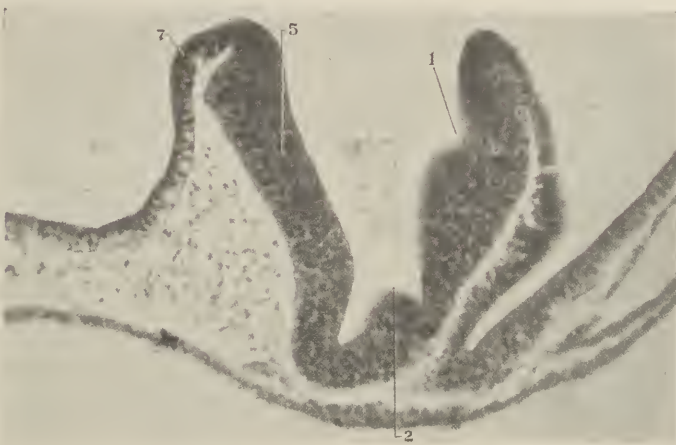


FIG. 15.—Transverse section of the embryo of four somites. (*Schulte and Tilney.*)

1. Optic sulcus. 2. Tubercle of the floor. 5. Medullary fold. 7. Somatic ectoderm.

loose, spongy tissue bordering upon the ventral and lateral surfaces of the neural folds. This tissue, *the mesenchyme*, is assuming a position favorable to the ultimate support and protection of the central nervous system. Along the outer edge of each neural fold, a few mesenchyme cells make their way inward by penetrating into the spaces between the larger ectodermal elements. This process marks the beginning of a mesenchymal invasion which lays the foundations for the blood vessels in the brain and spinal cord.

The *notochord*, which is situated ventral to the floor-plate throughout the greater part of its extent, fails to reach the cephalic extremity of the neural groove. This relation to the notochord determines the *epichordal* and *prechordal portions* of the neuraxis.

Probable Significance of the Neural Groove. The references already made to the neural groove indicate that in its cephalic extremity it is a deep and narrow cleft between the two opposing neural walls. The groove becomes more shallow and finally disappears in the caudal semicircular depression. In all embryos having an amniotic cavity the neural groove is,

for a considerable time, in open communication with the cavity of the amnion. In this manner the amniotic fluid comes into relation with the walls forming the neural folds. Inasmuch as the dense mass of cells forming these folds are not provided with blood vessels or lymph channels, they must have other means of obtaining nutrition. It is not improbable that this means is furnished by communication with the amniotic cavity, and that the process of metabolism is mediated through the amniotic fluid. In this sense, the central nervous system is primitively equipped with a system of irrigation entirely different from its ultimate condition. This system provides a direct method to satisfy nutritional demands and probably has its prototype in certain lower forms of life. In some of the invertebrates, the

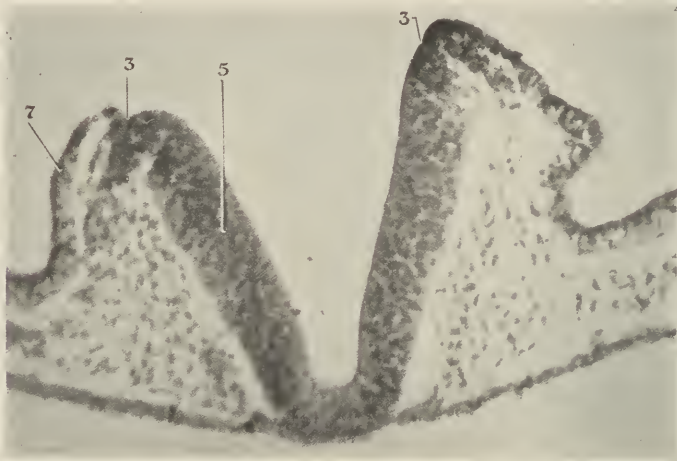


FIG. 16.—Transverse section of the embryo of four somites. (*Schulte and Tilney.*)

3. Trigeminal sulcus. 5. Medullary fold. 7. Somatic ectoderm.

nervous system is devoid of blood vessels and lymph channels; it depends for its nutrition upon a water-vascular system which furnishes a circulation for the central nervous organs. Water is received through the mouth and conducted thence to the brain by a tube known as the *neurobuccal duct*. It passes through a central canal corresponding in position to the neural groove and ultimately escapes from the nervous system through a caudal orifice or vent. This interpretation gives a new significance to the neural groove, which thus stands in a direct nutritive relation to the early development of the neuraxis pending the formation of an adequate system of blood vessels.

Differentiation of the Brain End of the Neural Folds. At this stage the head-end of the embryo is distinguishable, and the cephalic extremities of the neural folds present the two prominent evaginations from which the *retina* and the *optic nerve* take origin. Caudal to the optic evagination and corresponding to the position of the groove already noted in the stage of two somites, is a second outgrowth which has not reached the dimensions attained by the more cephalic protuberance of the eye. This caudal evagination is indicated by a shallow groove on the inner wall of the neural fold.

The chief difference between it and the optic evagination is that it does not contain an extension of the neural groove. The more caudal of the two sets of protuberances becomes the *trigeminal crest* from which the Gasserian ganglion develops.

A third pair of protuberances upon the dorsal aspect of the neural fold correspond in general character to the trigeminal crests. These outgrowths have a slight groove which indicates their position on the inner surface of the neural fold, but they contain no actual extension of the neural groove. They constitute the *acoustico-facial crests* from which arise the dorsal root ganglia of the *vestibular and cochlear divisions of the eighth nerve* and the *geniculate ganglion of the seventh nerve*.

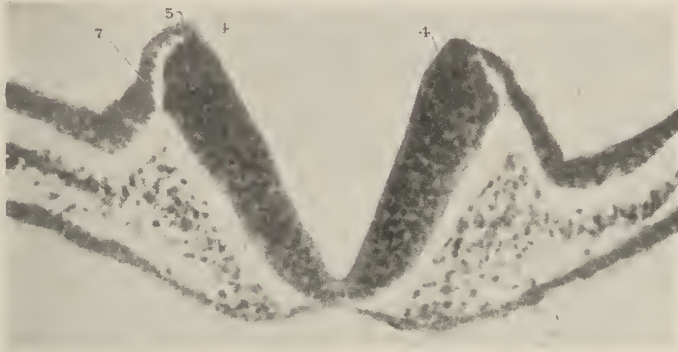


FIG. 17.—Transverse section of the embryo of four somites. (*Schulte and Tilney.*)

4. Acoustico-facial sulcus. 5. Medullary fold. 7. Somatic ectoderm.

THE STAGE OF EIGHT SOMITES

In this stage, certain critical changes have occurred which mark the inception of the transformation of the neural groove into a neural canal and the neural folds into an actual neural tube. The folds have undergone still further elevation, particularly in the head region. In many places these folds are nearly in contact, although at their most cephalic extremity they are still separated by a considerable distance.

Formation of the Roof-Plate and Neuropore. In one area, however, the folds have come into actual contact and a fusion across the middle line has been completed. The deep cleft between the neural walls of this region has in this manner acquired a roof. The fusion thus produced is limited in extent and involves but a small area in that part of the neuraxis which is to give rise to the brain. Caudal to this fusion the separation between the neural folds grows wider as the tail is approached. The region in which fusion has taken place presents three distinct topographical structures:

1. The two *lateral masses or walls* forming the lateral boundaries of the neural tube.
2. The *floor-plate* marking the original position of the neural groove.
3. The new element just formed by fusion at the summits of the lateral walls across the median line, the *roof-plate*.

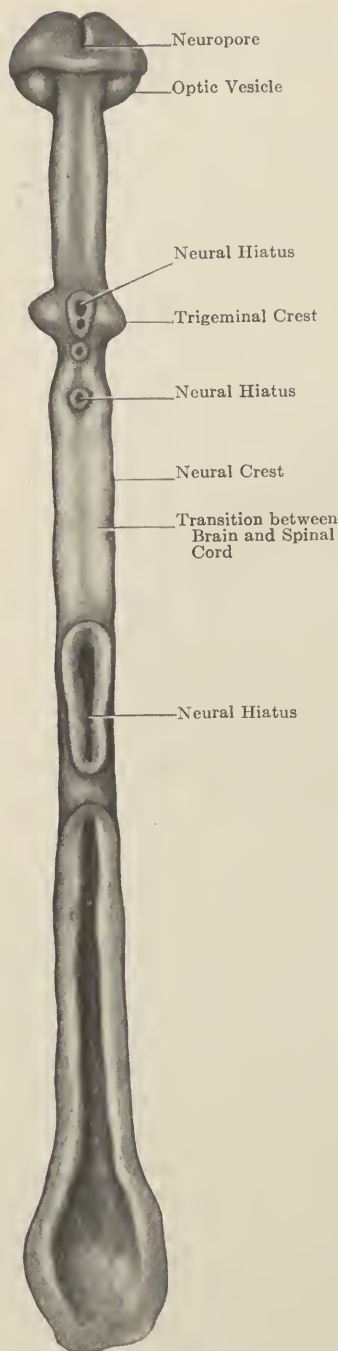


FIG. 18.—Reconstruction of the stage of ten somites showing the formation of the neuraxi. (Schulte and Tilney.)

Cranial of the fusion of the lateral walls across the midline, the neural folds are still widely separated, and bound an opening which is known as the *neuropore*. Caudal to the fusion forming the roof-plate, the separation between the neural folds is known as the *neural hiatus*.

The walls of the neural folds have at this stage shown no pronounced changes other than the thickening in the region of the head, and the greater elevation due to a massing of the cells as the cephalic extremity of the neuraxis begins to expand.

Fusion of the Somatic Ectoderm. The neural and somatic ectoderm present a further alteration in their relations. This is evident in the area where the neural folds have fused across the mid-dorsal line to form the roof-plate. At the point of this fusion the neural and somatic ectoderms are separated, and the somatic ectodermal layer, following the example of the neural cells, has formed a fusion across the mid-dorsal line. In this region there is a layer of somatic ectoderm stretched directly across the dorsal aspect of the roof-plate. In the more cranial regions the somatic and neural divisions of the ectoderm still maintain their original relations to the neural folds. This is also the case in the region immediately caudal to the roof-plate, in which position the neural folds are still separated from each other. This separation is more marked than in the region of the neuropore, although it is not difficult to appreciate in anticipation the course of events consequent upon complete fusion of the neural folds which results in the ultimate formation of the neural tube.

Invasion of Mesenchymal Cells. The mesoderm surrounding the neural folds, has increased in the number of its cells, and the evidence of the mesenchymal invasion into the folds is more marked than in the earlier stages. In some places there are clusters of mesenchymal cells which participate in the vascularization of the neural nervous system.

At this period the evaginations upon either



FIG. 19.—Transverse section passing through the optic vesicles of an embryo of eight somites. (*Schulte and Tilney.*)

1. Optic sulcus. 5. Medullary plate. 7. Somatic ectoderm.

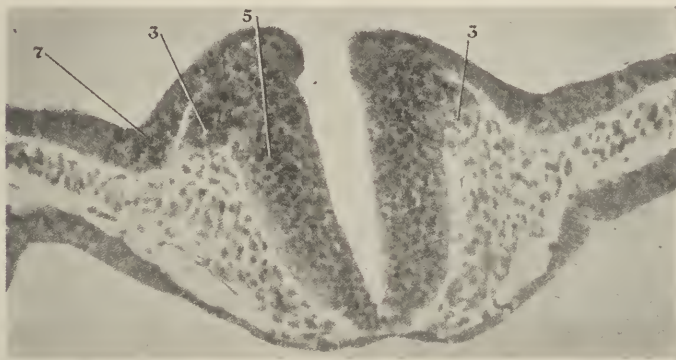


FIG. 20.—Transverse section passing through the anlage of the trigeminal ganglion of an embryo of eight somites. (*Schulte and Tilney.*)

1. Optic sulcus. 3. Trigeminal ganglion (the sulcus is still present). 5. Medullary plate. 7. Somatic ectoderm.



FIG. 21.—Transverse section passing through the anlagen of the acoustico-facial ganglia of an embryo of eight somites. (*Schulte and Tilney.*)

4. Acoustico-facial ganglion (the sulcus is still present). 5. Medullary plate. 7. Somatic ectoderm.

side of the cephalic extremity of the neural folds are the most conspicuous elements in the head region. These *optic evaginations* are not only the first to appear in the development of the tubes, but they are, in the early stages, the most conspicuous outgrowths from the brain. Both the *trigeminal* and *acoustico-facial crests* have increased in size.

Differentiation of Spinal Cord and Brain.

Immediately caudal to the acoustico-facial crest, the neural folds become reduced in all diameters, and although it is impossible to detect a definite constriction, the transition from the brain to the spinal cord is now discernible. A differentiation has finally been established between the part of the neuraxis which will give rise to the brain and the portion from which the spinal cord takes origin.

THE STAGE OF TWELVE SOMITES

Completion of the Roof-Plate. In this stage, the neural folds have almost completed their fusion across the mid-dorsal line. In the region cranial to the original formation of the roof-plate, the dorsal extremities of the neural folds have come into contact and fused, thus completing the roof-plate over the entire cephalic extremity of the brain. Caudal to the primary fusion of the neural folds, the roof-plate is now completed with the exception of several areas in which small apertures still persist. Two or three of these openings may be found immediately caudal to the position of the trigeminal crest.

At the caudal extremity of the neural folds, there is still a large opening, although the folds themselves are rapidly rising and approaching each other. With the exception of the several *hiatus* already mentioned and the large unfused region of the caudal extremity, the neural groove has been converted into a canal bounded by two lateral walls, a floor-plate and a roof-plate. The neural and somatic divisions of the ectoderm have separated from each other, except in the regions where the neural fusion is not yet complete. After separation the somatic ectoderm has

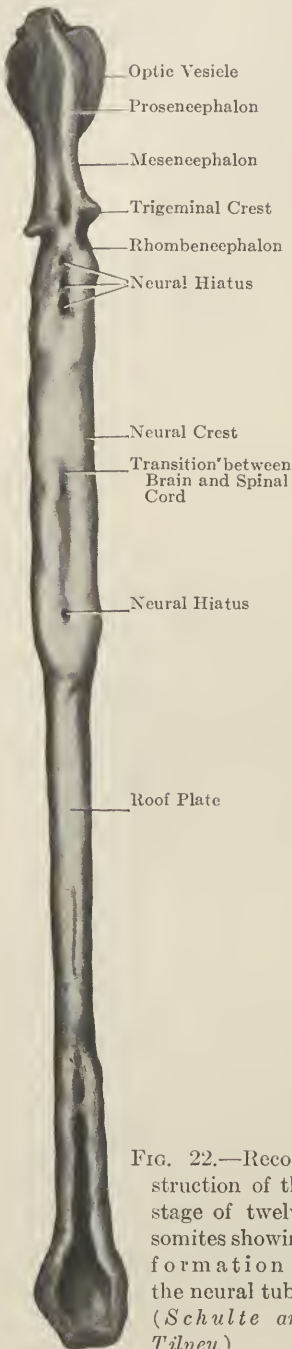


FIG. 22.—Reconstruction of the stage of twelve somites showing formation of the neural tube. (Schulte and Tilney.)

fused across the mid-dorsal line, forming an ectodermal covering over the

dorsum of the neural tube. As a result of this process the somatic ectoderm has detached itself from the neural ectoderm, at the same time concealing the neural tube beneath the surface and constituting a complete outer covering for the body.

Histological Changes in the Lateral Walls. Critical changes in the lateral walls have resulted in the formation of several strata of cells. The innermost of these cellular layers stains darkly and consists of two or three rows of cells. This is the *ependymal layer*. Adjacent to it is a less compact stratum. This constitutes the *mantle layer*, surrounding which is a thin, homogeneous mass, somewhat reticular in structure, containing but few cells and made up for the most part of nerve fibers. This is the *medullary layer*. Many karyokinetic figures appear in the ependymal layer indicating rapid cell multiplication, for this structure is the *germinal region* from which the new elements of the nervous system take origin. The cells constituting the mass

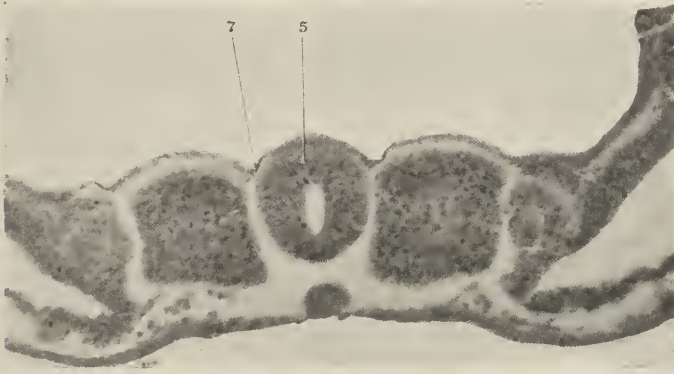


FIG. 23.—Transverse section of an embryo of sixteen somites, showing the closure of the neural tube completed prior to the appearance of the ganglionic crest. (*Schulte and Tilney.*)

5. Neural tube. 7. Somatic ectoderm.

of the mantle layer consist of *neuroblasts* and *spongioblasts*. The spongioblasts become differentiated to form the *neuroglia* or supporting tissue of the nervous system, while the neuroblasts give rise to the *neurocytes* or nerve cells, the active functional elements of the neuraxis.

Formation of Blood Vessels. Vascularization of the neural tissue has been carried to the point where it is possible to recognize that the mesenchymal invasion has given rise to many isolated *blood vascular spaces* which, by their confluence, have formed a rich intramedullary plexus of capillary vessels.

The Neural Crests. Along the dorsal aspect of the neural tube, upon either side of the roof-plate, there appears a long ridge of cells produced by a protrusion from the lateral walls, the *neural crests*. These two crests are parallel with each other and extend along the neural tube as the direct caudal continuation of the trigeminal and acoustico-facial crests.

Upon histological examination, the neural crests appear to be made up

of the same type of cells as those in the mantle layer. It is, in fact, due to migration of cells from the dorsal region of the mantle layer that the two neural crests are formed. The crests ultimately give rise to the spinal ganglia which, in this light, are intrinsic parts of the central nervous system, but have by a subsequent process of migration moved away from their points of origin.

Increase in the Number and Differentiation of the Somites. The mesenchyme at this period has undergone considerable modification. It has formed a series of body segments or somites extending from the brain toward

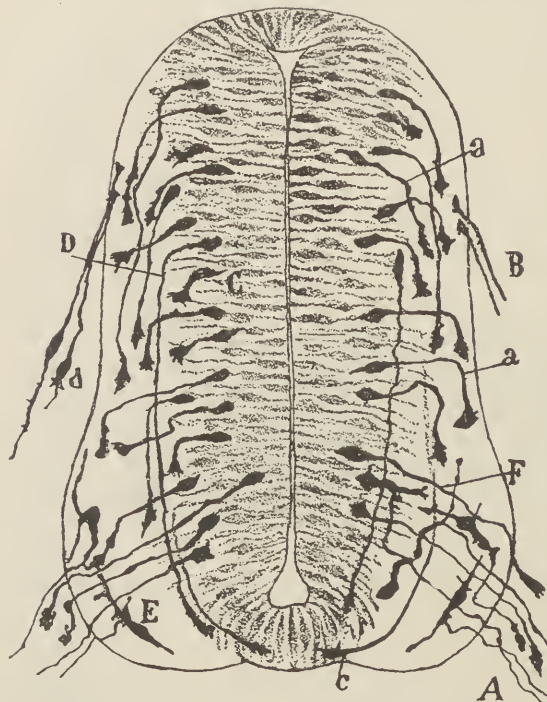


FIG. 24.—Cord of an embryo chicken at 3d day of incubation. Golgi's method. (Cajal.)

A—Anterior root. B—Posterior root. C—Primitive neuroblast. D—Commissural neuroblast. E—Motor cells already supplied with dendrites. F—Motor neurone provided with its cone of growth. a—Neuroblast supplied with an internal branch. c—Commissural cone of growth. d—Sensory bipolar cell.

the caudal pole. These somites are arranged in pairs, one upon either side of the neural tube. They consist of a dense mass of cells which stain deeply and in which three divisions may be distinguished. The mesial portion of each mass of cells appears as a thick plate with a concave surface turned toward the neural tube. The ventral and lateral portion of the somite consists of a more irregular mass of cells, while the dorsal portion is a thin plate with its convexity turned toward the ectoderm. This is the *cutis plate*, which subsequently participates in the formation of the dermatomes or cutaneous segments of the body.

The irregular ventro-lateral mass of cells is the *myotome* from which arise the segmental muscular structures, while the mesial

mass of the somite is the *sclerotome* from a portion of which the bony structures surrounding the neural tube take origin. Each pair of somites is separated from the next succeeding pair by an appreciable interval in which there is a rarefaction of the mesenchyme cells. The somites are not in direct contact with the neural tube, being separated from it by a considerable mass of interposed mesenchymal cells. These cells form a loose, spongy tissue. The line of contact between the mesenchymal cells and the neural tube is characterized by a denser layer containing a rich capillary network of blood vessels. This condensation of the mesenchyme, perineural in position and

directly contiguous with the neural tube, marks the beginning differentiation of the innermost of the membranes which cover the neuraxis, the *pia mater*.

Increase in Size of Brain-Vesicle. Due to the fusion of the neural folds across the midline, the neural groove is converted into an almost completely closed *neural* or *central canal*. The openings which it presents are formed by the several *hiatus* in the roof-plate, as well as a wide aperture at the caudal extremity of the tube.

A marked change has occurred in the relative size of the optic evaginations. In the earlier stage, these vesicles were prominent; they were nearly

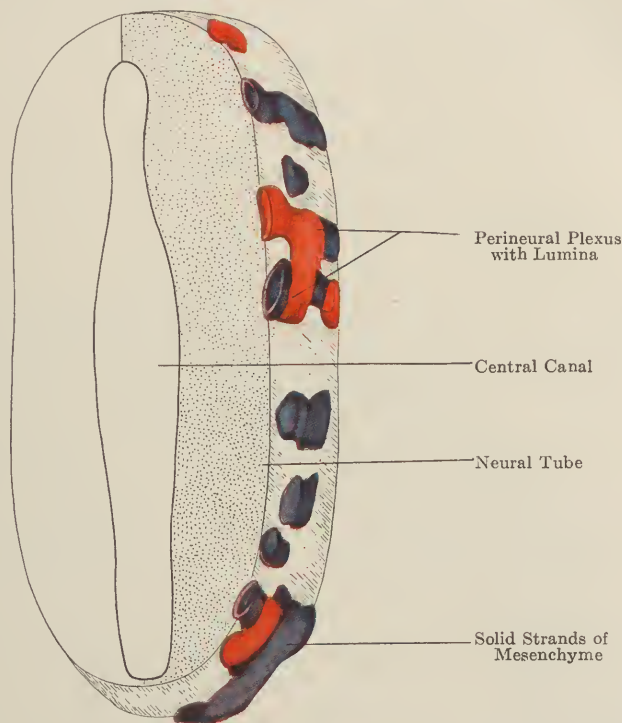


FIG. 25.—Formation of the perineural plexus in the 3.5 mm. albino rat embryo. These vascular spaces develop in the perineural mesenchyme.

equal in size to the part of the brain from which they arose. At this stage, the brain has grown much more rapidly than the optic evaginations. The growth which has produced this inequality in size has particularly affected the dorsal area of the brain-vesicle, so that the optic evaginations seem to have moved forward into a position more ventral than the one they formerly occupied. The change in size is only apparent, however, since there is no absolute decrease in the dimensions of the optic evaginations.

Primitive Divisions of the Brain. A more important advance in this stage is brought about by the appearance of certain divisions in the neural tube. The most cephalic portion of the neuraxis now has the greatest dimension. Immediately succeeding it is a constricted portion followed by a second

dilatation of the neural tube. In this manner the *three primitive vesicles of the brain* are differentiated. The first of these is the *prosencephalon* or *forebrain*; the second and smallest portion is the *mesencephalon* or *midbrain*, while the third or caudalmost portion is the *rhombencephalon*. From these three primitive vesicles arise all of the parts in the adult brain.

The Myelomeres. The spinal cord has also shown a tendency toward division. This, however, is incident to the development of the somites, for in the region of each pair of body segments, the spinal cord becomes somewhat constricted. This gives it the appearance of a series of long, undulating indentures separated by narrow, unconstricted portions of the tube. Each one of these long constrictions constitutes a myelomere. Although its presence may be considered as incidental to the development of the somite, each myelomere has the significance of an actual segment of the neural tube. This fact is further emphasized by the behavior of the neural crests, which become segmented into portions corresponding exactly with the myelomeres. In this light the myelomere becomes something more than the mechanical expression of the developing somite. It furnishes the basis for the conception that the central axis of the nervous system is actually a segmented structure.

The Encephalomeres. In the rhombencephalic portion of the brain, similar divisions or segments are observed. These have been variously estimated as five to nine in number, while in the mesencephalic portion of the brain two or three such segments have been identified. The segments in the cranial portion of the neural tube have a history of development totally different from those in the spinal portion, so that it seems unwarranted to consider these two sets of neural segments as homodynamous, that is, as dynamically the same. The brain segments are called *encephalomeres* to distinguish them from the spinal segments or myelomeres. The encephalomeres, although not influenced by the presence of somites, are dependent upon a different type of body segmentation which occurs in the head region, the *branchial segments*. The point which requires emphasis, however, is that the encephalomeres or brain segments are different in their development and probably in their functional significance from the spinal segments or myelomeres.

CHAPTER III

THE EMBRYOLOGICAL DEVELOPMENT OF THE CENTRAL NERVOUS SYSTEM (*Continued*)

THE STAGE OF TWENTY-SIX AND THIRTY SOMITES

The Central Canal and Primary Flexures. The principal changes observed at this stage result from the complete closure of the neural groove and its conversion into a central canal. This canal is relatively smaller than at any of the previous stages described, due to the rapid growth of the walls, the roof-plate and the floor-plate bounding it. In the cephalic portion of the neural tube, it constitutes the ventricular chambers of the

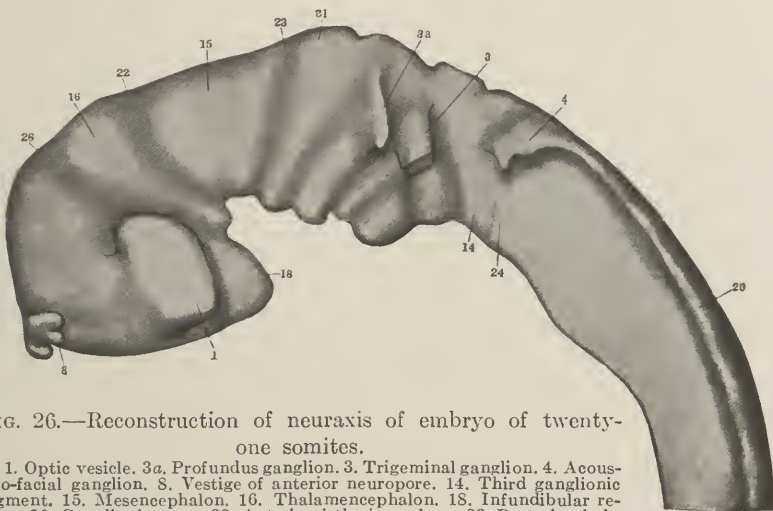


FIG. 26.—Reconstruction of neuraxis of embryo of twenty-one somites.

1. Optic vesicle. 3a. Profundus ganglion. 3. Trigeminal ganglion. 4. Acoustic-facial ganglion. 8. Vestige of anterior neuropore. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 18. Infundibular region. 20. Ganglionic crest. 22. Anterior isthmic sulcus. 23. Posterior isthmic sulcus. 31. Preganglionic segment of deuterocephalon. (*Schulte and Tilney.*)

brain. Another feature at this stage is the appearance of two flexures in the cerebrospinal axis, the most important of which occurs near the cephalic extremity of the tube at the junction of the forebrain with the midbrain. This is the *cephalic flexure*. As the result of this flexure, the forebrain is bent so that its long axis is almost at right angles to the long axis of the midbrain. The second flexure occurs at the junction of the spinal portion of the neural tube and the rhombencephalon. This is the *spinal* or *cervical flexure*.

The Secondary Brain-Vesicles. An important change is determined by the appearance of the five secondary brain-vesicles. In the most cephalic portion of the prosencephalon a protrusion occurs which marks the beginning of the *telencephalon* or *endbrain*, while the remaining portion of the

primitive prosencephalon becomes the *diencephalon* or *interbrain*. The mid-brain presents no further subdivision and remains but little altered.

In the rhombencephalon, it is now possible to recognize two vesicles. The cephalic half of this primary vesicle shows a decided expansion in all its diameters. Dorsally, the roof-plate develops a slight protrusion, the lateral walls are increased in their dimensions and the region of the floor-plate presents a noticeable enlargement. This expansion in the cephalic extremity of the rhombencephalon gives rise to the *metencephalon* or *hindbrain*, while the remaining, unexpanded portion of the original rhombencephalic vesicle is the *myelencephalon* or *afterbrain*.

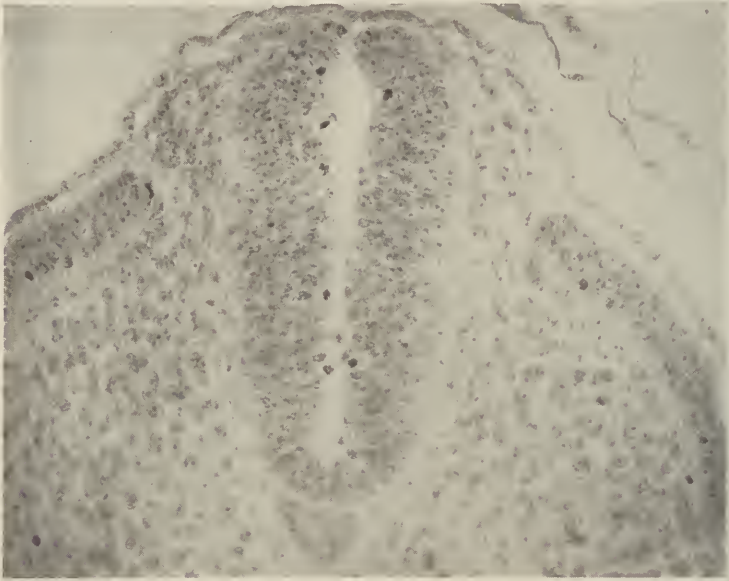


FIG. 27.—Cross section showing the neural tube in a twenty-one somite cat embryo.

Differentiation of the Ventral and Dorsal Gray Columns. The appearance of the neural walls has undergone histological alteration dependent upon a thickening of the several layers of cells. The ependymal layer is still actively engaged in the karyokinetic process. The mantle layer has increased in size and shows a disposition to a rearrangement of its cellular elements. The most conspicuous among these changes is the migration of the cells in a ventral direction. Many of these cellular elements are becoming differentiated as *neurocytes* and long processes may be detected extending from them toward the periphery of the neural tube. This change represents the first differentiation which produces the characteristic features of the nerve cell, the distinction of the *soma* or *body* of the cell from its *axone* or chief conducting process. The extension of the neuroblasts into the ventral portion of the neural tube is the first step toward the formation of the *ventral gray column* of the spinal cord. A similar migration of cells occurs in the myelencephalon, in the metencephalon and to some degree in the mesencephalon;

but above this level the tendency to the formation of a ventral gray column is not so distinct as in the spinal cord. The cells of the dorsal portion of the mantle layer have migrated dorsally and thus form the beginning of the *dorsal gray column*. The intermediate mass of cells between the dorsal and ventral columns constitutes the body of the gray matter of the cord.

The Medullary Layer and Capillary Plexus. Surrounding the mantle layer is a thickened layer, indicating a rapid increase in the number and size of the axones which have entered into the medullary substance of the central axis. A rich intraneural capillary plexus furnishes the means of blood supply. This plexus is in direct connection with a dense, perineural plexus



FIG. 28.—Cross section of the neuraxis in a 3.5 mm. embryo of the white rat, showing the invasion of the mesenchyme cells into the walls of the neural tube from the perineural capillary plexus.



FIG. 29.—Cross section of the neuraxis in an 8.5 mm. embryo of the white rat, showing the development of the endoneural vascular plexus at the height of its efflorescence from the confluence of individual blood spaces.

situated in the inner membrane covering the cord and the brain, the *pia mater*. By a process of delamination, this membrane is separating from the surrounding mesenchyme, which in turn is becoming thicker preparatory to the formation of the *dura mater*. At regular intervals along the course of the spinal cord, corresponding to the position of the neuromeres, nerve fibers leave the ventral gray columns and make their way toward the myotomes. These fibers constitute the ventral roots of the spinal nerves.

The Oculomotor and Trochlear Nerves. Certain of the cranial nerves have made their appearance in connection with the secondary brain vesicles. Two of these are related to the midbrain, namely, the *oculomotor* or *third*

cranial nerve and the *trochlear* or *fourth cranial nerve*. The fibers of the third nerve emerge from the ventral surface of the neural tube, while those of the fourth nerve make their emergence from the dorsal aspect. Neither of these nerves is, at any time, in relation with elements corresponding to the neural crest. They are purely motor nerves and represent the innervation of certain head segments whose subsequent development leads to the production of the extrinsic muscles of the eye-ball.

The Trigeminus, Facial and Acoustic Nerves. In the region of the metencephalon, a large sensory nerve is distinguished in connection with the



FIG. 30.—Cross section of the neuraxis in an 11 mm. embryo of *mus decumanus*, showing the deflorescence of the endoneural vascular plexus.

Gasserian or *trigeminal ganglion*, a structure derived from the evagination which made its appearance immediately caudal to the optic evagination. Ventral to the Gasserian ganglion are a few axones which emerge from the more ventral portion of the neural tube. These constitute the motor fibers of the *trigeminus* or *fifth nerve*. In a still more caudal position of the metencephalon are the ganglionic elements of two other nerves, the *acusticus* or *eighth nerve* and the *facialis* or *seventh nerve*. The nerve fibers themselves are in connection with a single ganglionic structure which later becomes differentiated as two distinct ganglia, the *geniculate ganglion* of the facial nerve and the *acoustic ganglion* of the auditory nerve. The acoustic ganglion subsequently subdivides to form the *vestibular*

ganglion of Scarpa and the *spiral* or *auditory ganglion of Corti*.

The Glossopharyngeus, Vagus, Accessorius and Hypoglossus Nerves. Four nerves are connected with the myelencephalon; the *glossopharyngeus* or ninth nerve, the *vagus* or tenth nerve and the *hypoglossus* or twelfth nerve. In part incorporated with the tenth nerve and in part making its ascent along the lateral aspect of the neural tube from the upper cervical segments of the cord is a fasciculus of nerve fibers which constitutes the eleventh or *spinal accessory nerve*. The vagus and glossopharyngeus nerves are comprised of efferent and afferent fibers; they are connected with a large ganglionic mass which eventually gives rise to their respective root ganglia.

Ganglion of Froriep and Ganglion Accessorius. A small ganglionic mass is primitively in connection with the motor fibers of the hypoglossal nerve. This mass subsequently disappears and the twelfth nerve is ultimately

devoid of ganglionic elements. The collection of nerve cells attached to the hypoglossal nerve at this period is known as the *ganglion of Froriep*; its presence indicates that the hypoglossus was originally a mixed sensorimotor nerve. It eventually delegated its sensory function to the chief sensory nerve of the head, the *trigeminus*. The spinal accessory nerve, while making its ascent along the lateral aspect of the neural tube from the upper cervical segments to the myelencephalon, is covered by the migrating mass of the neural crest. It seems to come into definite relation with a ganglionic element known for this reason as the *ganglion accessorius*. This relation,



FIG. 31.—Cord, spinal and sympathetic ganglia, terminal muscular arborization; embryo of a chicken at 5th day of incubation. Golgi's method. (Cajal.)

A—Anterior root. B—Posterior root. C—Motor cells. D—Sympathetic ganglion. E—Cells of spinal ganglion at the bipolar stage. F—Anterior branch of spinal pair. a—Motor fiber bifurcated twice. b—Embryonic motor arborization. c—Motor arborization in muscles of the back. d—Posterior motor division. e—Sensory nerve.

however, is one of contiguity only. The spinal accessory nerve comprises fibers exclusively of the motor or efferent type.

Segmentation of the Neural Crest. The neural crest during this period has developed salient changes which mark a critical advance. The first of these changes appears in a segmentation of the crest into more or less equal parts, beginning at its cephalic extremity and extending caudally for a considerable distance. This segmentation results in the formation of collections of nerve cells situated on the dorso-lateral aspect of the neural tube and grouped in pairs. Each pair is in direct relation with a myelomere.

The Spinal Ganglia. These paired collections of nerve cells represent

the inception of the formation of *dorsal root ganglia*. Each pair of ganglia shows a tendency to migrate away from its original position along the lateral aspect of the neural tube. The ganglia, however, do not entirely detach themselves from the positions of their origin, but, during their migration, maintain their connections with the neural tube by means of fine fibers. These nerve fibers which establish the connection between the dorsal root ganglion and the spinal cord constitute the *dorsal roots*. Each pair of ganglia with its attached dorsal root fibers is connected with a corresponding myelomere of the spinal cord. The formation of dorsal root ganglia, beginning in the

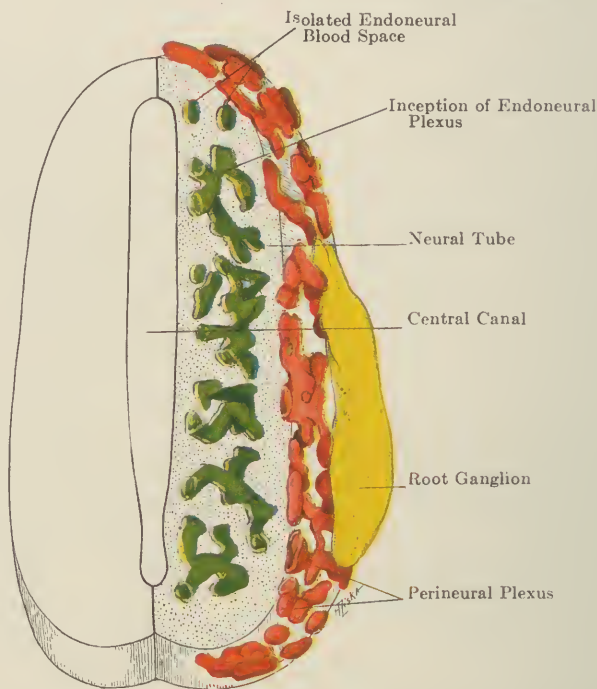


FIG. 32.—Formation of the perineural and endoneurial plexus in the 5.5 mm. albino rat showing the independent development of these two systems of channels.

cephalic portion of the neural tube, is in process throughout the entire length of the axis. It is much retarded in the caudal extremity, however, for here the neural crest still shows little tendency to divide into segmental ganglionic masses.

Constituents of a Typical Spinal Segment. Further evidence of the segmental character of the spinal cord is found in the appearance, at this stage, of nerve fibers which arise from the myelomeres and make their way outward as separate fasciculi to connect with the corresponding myotomes. These nerve fibers are the early axis cylinder processes of the cells which differentiate in the ventral gray column. They constitute the *ventral roots*. In the adult each segment of the spinal cord is composed of (1) *one myelomere* in connection with which is (2) *a pair of dorsal root ganglia*; (3) *a pair*

of dorsal roots and (4) a pair of ventral roots. These are the structural elements entering into the formation of a typical spinal segment.

The Optic Stalk and End-Vesicle. The evaginations noted in the earlier stages have undergone considerable change. The optic evagination is now in connection with the diencephalon. It shows some modifications dependent upon the relative reduction in its proportions as compared with the forebrain. The evagination has become slightly constricted near the region of its continuity with the wall of the interbrain, while its distal portion is expanded to form an end-vesicle. In this stage, the optic evagination

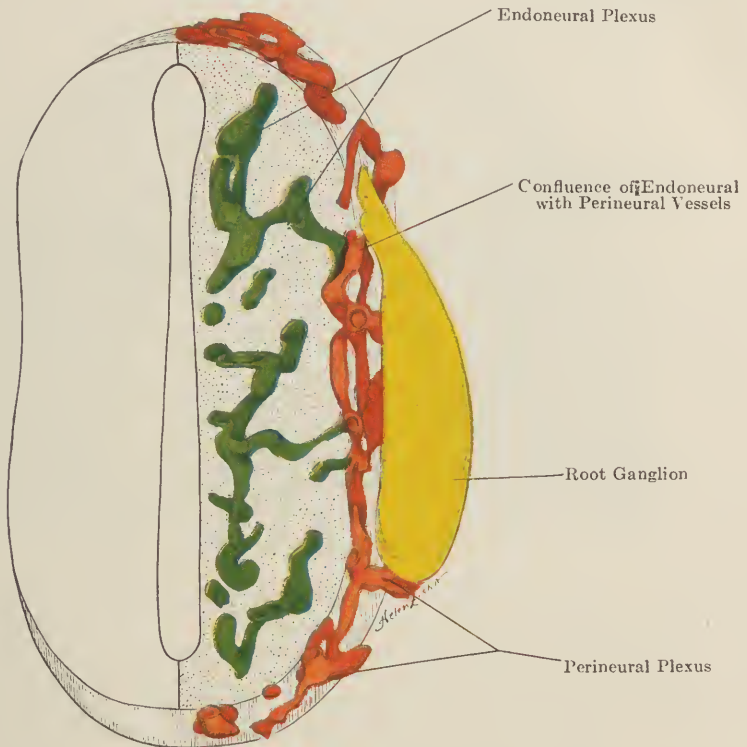


FIG. 33.—Formation of the perineural and endoneural vascular plexus in a 7 mm. albino rat, showing the beginning confluence of these two systems of vascular channels.

presents an *end-vesicle* and a *proximal portion* or *stalk* which connects it with the interbrain. The eye-cup develops from the end-vesicle out of which arise the retinal portions of the eye. Axones from retinal cells extend into the optic stalk to form the *optic nerve*, *chiasm* and *tract*. Both the stalk and the end-vesicle retain their original lumen; the ventricle of the interbrain at this period is in connection with a large recess in the optic evagination by means of a canal extending through the optic stalk.

The Trigeminal and Acoustico-Facial Evaginations. The evaginations of the early stages marking the trigeminal and acoustico-facial nerves have

lost their original diverticular character. They have become ganglionic masses which participate in the formation of the Gasserian ganglion and of the ganglia connected respectively with the acoustic and facial nerves.

The Infundibular Evagination. Another evagination of importance has made its appearance in connection with the neural tube. This is a diverticulum which appears in the floor-plate of the forebrain at its caudal extremity, the *infundibular evagination*. This evagination gives rise to the infundibular stalk and process. It assumes importance because it subse-

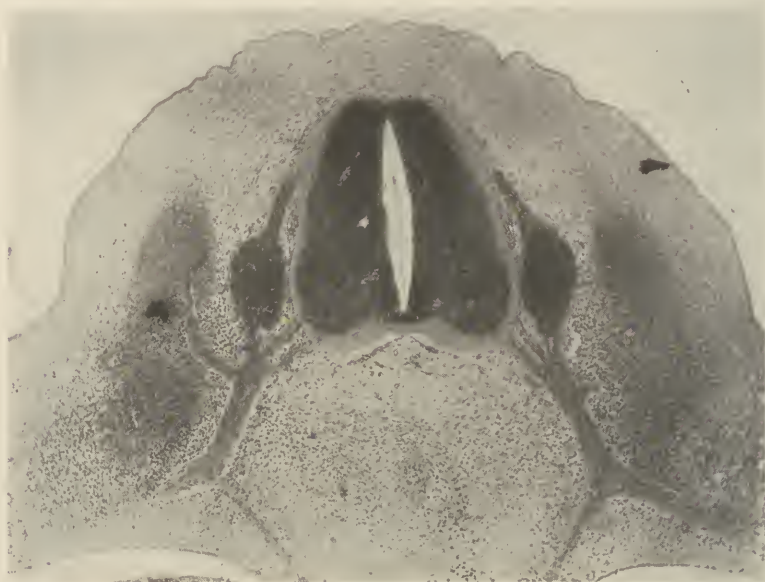


FIG. 34.—Transverse section through a 14 mm. pig embryo showing the characteristics of a typical spinal segment. The neural tube with its narrow central canal occupies a central position; attached to it are the ventral and dorsal spinal roots. Each pair of dorsal roots has connected with it a pair of dorsal root ganglia. The dorsal and ventral roots fuse to form a pair of mixed nerves (motor and sensory). Each pair of mixed nerves divides into a primary dorsal and ventral branch. Each pair of primary ventral branches is connected with the sympathetic system by a pair of rami communicantes.

quently comes into relation with an evagination of the mouth cavity, the *oral pocket of Rathke*, from which the pituitary gland takes origin. The pituitary gland and infundibular process together constitute the *hypophysis cerebri*.

The Otocyst. An invagination from the somatic ectoderm develops at this stage and establishes ultimate relation with the nervous system. This invagination occurs in the somatic ectoderm in the region bordering upon the metencephalon. It is at first a deep indenture in the surface which rapidly is converted into a hollow sac situated beneath the ectoderm and in contact with the neural tube. When finally converted into the oval sac, it

is known as the *otocyst*. It establishes relations with the seventh and eighth nerves and gives rise to the membranous internal ear, including the *semi-circular canals and their ampullæ*, the *sacculæ*, the *utricle*, the *canalis reuniens*, the *cochlea* and the *ductus endolymphaticus*.

The stage of twenty-six somites marks the appearance of the *five secondary vesicles* of the brain.

It is characterized by the further differentiation of the structures from which spring two important end-organs of special sense, the *eye* and the *ear*.

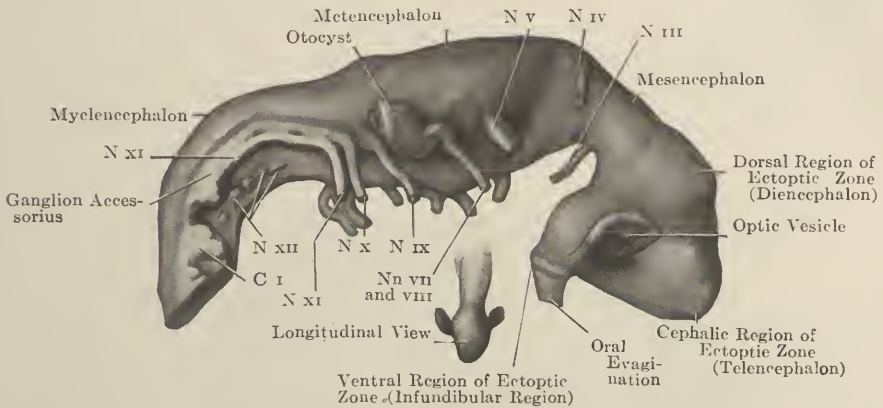


FIG. 35.—Reconstruction showing stage of $6\frac{1}{2}$ mm. (thirty somites); the secondary brain vesicles in *felis domestica*.

It gives final evidence of the segmental character of the spinal cord in the *myelomeres* and the *segmented ganglionic masses*, the *dorsal root ganglia*.

It also indicates the inception of a segmental process in the brain which results in the formation of the *encephalomeres*.

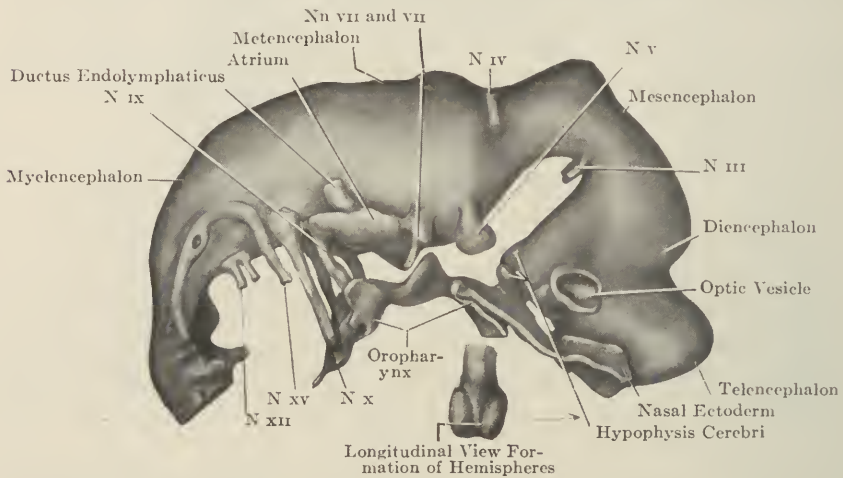
It contains the beginning of the process which results in the formation of the *hypophysis cerebri*.

THE STAGE OF SEVEN AND ONE-HALF, EIGHT AND ONE-HALF, AND ELEVEN MILLIMETERS—THIRTY-ONE SOMITES

Aula and Hemispherium. The five secondary vesicles show considerable advance in their development. This is especially the case in the telencephalon which, at the stage of twenty-six somites, presented a simple extension in a dorso-ventral direction of the main body of the original prosencephalic vesicle. It is now possible to recognize two lateral additions to this original median expansion of the forebrain. The endbrain thus consists of a median and two lateral portions. The median element is the *aula*. A groove upon either side separates it from the two lateral expansions which are symmetrical and have a tendency to extend forward beyond the aula. Each of these lateral expansions constitutes the *hemispherium* from which each *cerebral hemisphere* takes its origin, while the aula contains the *cephalic portion of the third ventricle* and has its cephalic limit in the *lamina terminalis*.

The mesencephalon is still a large vesicle separated from the diencephalon by the *anterior isthmian sulcus* and from the metencephalon by the *posterior isthmian sulcus*. The metencephalon and myelencephalon, with the exception of an increase in their diameters, show little change.

The Sulcus Limitans. A longitudinal groove divides each lateral wall of the neural tube into a ventral and a dorsal zone. This groove is the *sulcus limitans*. The portion of the lateral wall ventral to the sulcus is the *basal plate*, while the portion of the wall dorsal to it is the *alar plate*. The sulcus limitans may be traced as far cephalad as the diencephalon. The lateral walls of the neural tube show considerable increase in their diameters, due to a rapid accumulation of neuroblasts in the basal plate, especially in the region of the ventral gray column. In the alar plate, the cells are forming the dorsal gray column, and the intermediate region between the two columns consti-



[Fig. 36.—Reconstruction showing stage of $7\frac{1}{2}$ mm. (thirty-one somites) in *felis domestica*.

tutes the body of the gray substance. The velum has increased in thickness by the addition of many fibers which participate in forming the medullary substance. A concentration of cells similar to that in the basal plate of the spinal cord may be observed in the region of the myelencephalon and metencephalon, but in both of these vesicles the tendency to the formation of a definite ventral gray column is less pronounced than in the cord. This is also the case with the dorsal gray column in the regions just mentioned. In the midbrain and interbrain this tendency to form the two columns in the gray matter is not apparent.

Histologically, the cells collected in the basal plate are distinctly larger than those assembled in the alar plate. This is regarded as evidence of a process of motor differentiation in the region ventral to the sulcus limitans and of sensory differentiation dorsal to it.

Formation of the Membranes. The mesenchyme which surrounds the neural tube has undergone further differentiation and it is possible to dis-

tinguish three connective tissue coverings surrounding the cord, the *pia mater*, the innermost; the *dura mater*, the outermost and the *arachnoid*, interposed between them. Each of these membranes appears to be a definite lamination of the paraxial mesoderm. Between the *dura mater* and the *arachnoid* there is a considerable space which has the appearance of containing fluid. This is the *subdural space*. An even greater interval exists between the inner surface of the *arachnoid* and the *pia mater*. This is the *subarachnoid space*, in which is contained the *cerebrospinal fluid*. A condensation of the mesenchyme has been carried to the point where it is possible to identify the *protovertebrae* or the *primitive vertebral bodies*. These are laid down in cartilage and contain in their center the remnant of the notochord. Lateral to the neural tube are the pedicular and laminar processes of the *vertebrae*. At regular intervals between these pedicles and laminae are the *interverte-*

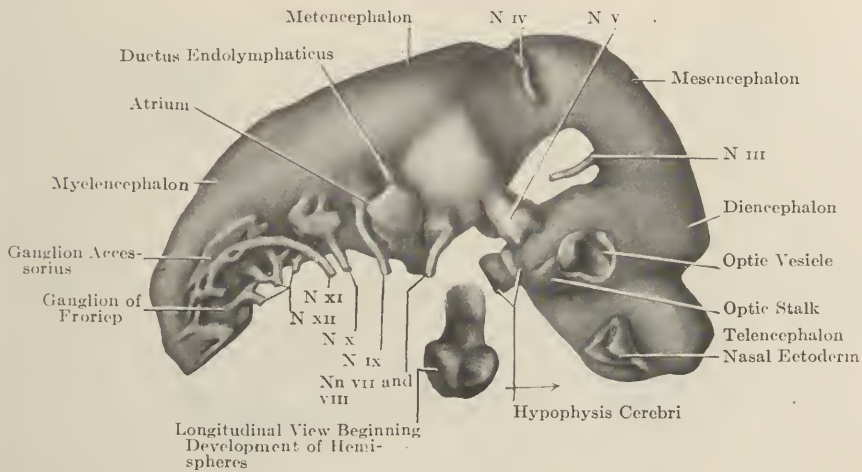


FIG. 37.—Reconstruction showing stage of $8\frac{1}{2}$ mm. (thirty-one somites) in *felis domestica*.

bral spaces which are important because of their relation to the dorsal root ganglia.

The Cranial Nerves. The cranial nerves have been increased in number by the appearance of the olfactory nerves which are discernible in connection with each hemisphere. A slender fasciculus of nerve fibers connects the end-brain with an invagination of the ectoderm in the nasal region. This invagination is formed by specialized ectodermal cells constituting a sensory mechanism known as the *olfactory placode* from which the olfactory mucous membrane takes origin. In this way the olfactory mechanism is provided with its receptors in the nasal cavity.

The optic end-vesicle has become relatively smaller in size in comparison with the rest of the brain and has moved laterally away from its connection with the diencephalon. It is still attached to the floor-plate of the interbrain by means of an attenuated stalk in which appear the axonal processes of

the retinal cells in the optic end-vesicle. These fibers are so arranged as to form a heavy bundle crossing from one side to the other in the floor-plate of the diencephalon. Their course at this stage identifies the beginning of the *optic nerve* and the *optic chiasm*.

The other cranial nerves connected with the midbrain, the hindbrain and the afterbrain, show little alteration, except that the ganglia in the case of the mixed nerves have migrated still further from their original median position and are situated ventro-lateral to the neuraxis. The motor roots have extended further from their points of origin and have penetrated the myotomes which they supply.

The Spinal Ganglia and Their Roots. The dorsal root ganglia in the spinal portion of the neuraxis have migrated into the intervertebral spaces and are invested by the three coverings of the cord, the pia mater, the dura

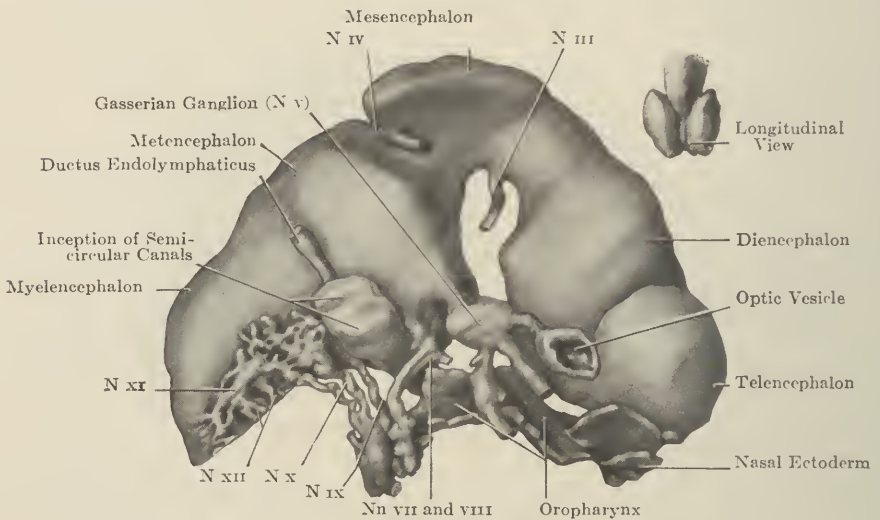


FIG. 38.—Reconstruction showing stage of 11 mm. in *felis domestica*.

mater and the arachnoid. They are lodged in special evaginations formed by the two inner coverings which invest them loosely. The peripheral arms of axones from the dorsal root ganglion cells may be traced into the mesenchyme, and some of them extend as far as the *cutis plate* of the somite. This outgrowth of nerve fibers indicates the means by which the future *dermatomes* or skin segments of the body are innervated.

The Formation of the Sympathetic Ganglia. A change of importance involving the dorsal root ganglia occurs in a migration of ganglionic neuroblasts into the loose mesenchyme ventral to the protovertebræ. This migration extends inward and forward toward the median line. Immediately dorsal to the aorta and at regular intervals along its course, collections of neuroblasts assume the form and arrangement of *vertebral ganglia*. These structures ultimately are arranged as two vertebral chains of ganglia situated dorsal to the aorta. This is the beginning of the *sympathetic system* and

represents the inception of the *ganglionated sympathetic cord*. The cells which have migrated to form the vertebral ganglia do not sever their connection with the dorsal root ganglia. They maintain an attachment to the root fibers by means of slender bundles of nerve filaments which constitute the *white rami communicantes*. The sympathetic system develops as an accessory to the central axis but retains its connections by means of these communicating branches.

The Hypophysis and Otocyst. The infundibular evagination has increased in size and is in contact with a corresponding evagination from the mouth cavity, *Rathke's pocket*. The two are not only in contact but have fused, thus forming the *hypophysis cerebri*. The infundibular evagination gives rise to the neural portion of that structure, while the evagination from the mouth cavity forms the glandular portion. The otocyst also has under-

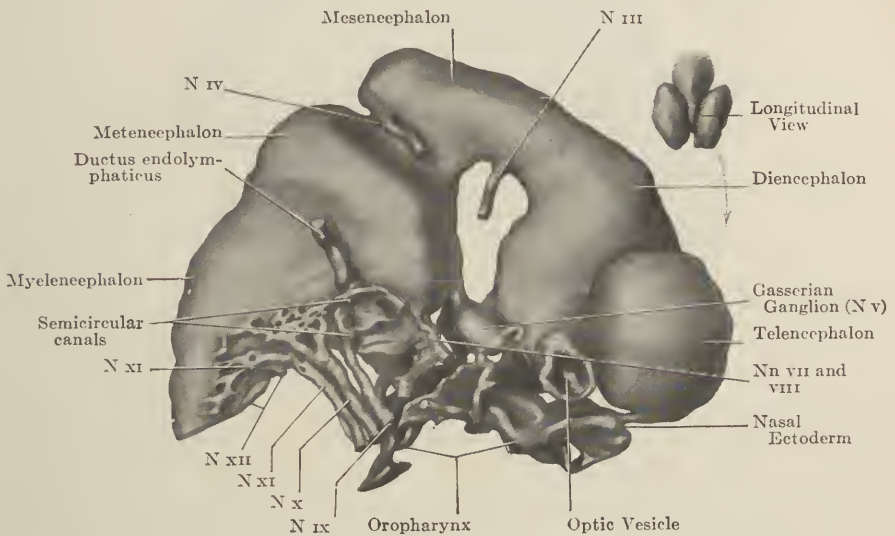


FIG. 39.—Reconstruction showing stage of 12½ mm. in *felis domestica*.

gone further differentiation. In addition to the simple oval sac first developed, it has produced a lateral diverticulum situated close to the neural wall. This is the *ductus endolymphaticus*. The original portion of the otocyst is known as the *atrium*.

STAGE OF TWELVE AND ONE-HALF, FOURTEEN, SEVENTEEN AND TWENTY-SIX MILLIMETERS

The Telencephalon. In these comparatively late stages of embryonic development, all of the definitive elements of the nervous system are laid down, and further changes in them depend solely upon expansion and growth. A notable difference in the relations of the two portions of the telencephalon, the hemispherium and the aula, is the fact that the hemispheres have become the predominant structures and have completely

concealed both the tectum and the diencephalon. Subsequent changes in the brain are dominated by this rapid growth of the hemispheres which, although the latest elements to appear, become the largest structures of the encephalon.

The Diencephalon. The walls of the diencephalon have become thickened, and it is possible to recognize in them the subdivisions of the thalamus and the hypothalamus. The floor-plate of the interbrain shows no change except the elongation of the optic nerve and the migration of the eye cup

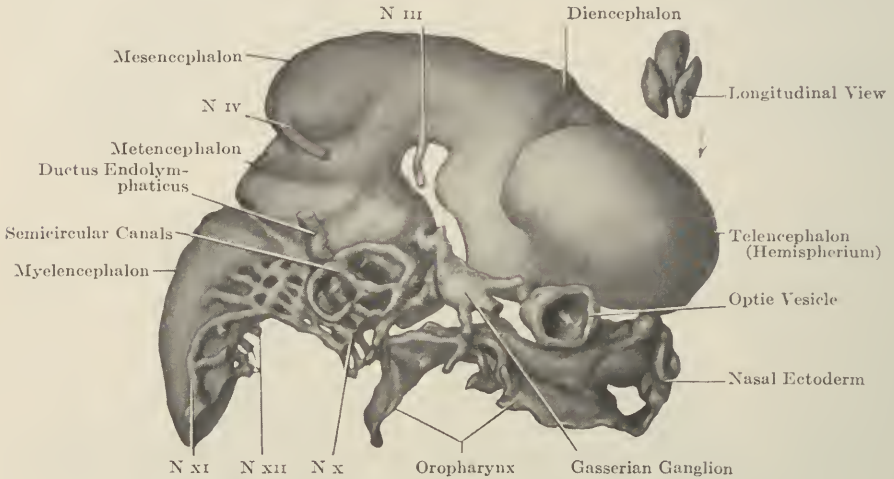


FIG. 40.—Reconstruction showing stage of 14 mm. in *felis domestica*.

away from the brain. The end-vesicle, by a process of invagination, has formed a two-layered optic vesicle with a concave fundus. The infundibular evagination has been surrounded by Rathke's pocket and the neural portion of the hypophysis is almost completely invested by the ectodermal cells forming the glandular portion of that organ. The oral evagination of the pituitary body is gradually separating from the mouth cavity, although it is still connected with the roof of the mouth by means of a narrow stalk.

The Mesencephalon. The mesencephalon has increased considerably in size, especially in the region of the roof-plate, and contains a large ventricular cavity.

The Metencephalon and Myelencephalon. This division of the brain has increased in size, both in its ventral and dorsal aspects. The roof-plate presents a large dorsal protrusion which is the central arch of the cerebellum. This arch is connected upon either side with an evagination, the *lateral cerebellar evagination*. Ventrally the hindbrain has developed a marked protuberance, the *pontile flexure*, in connection with which the *pons Varolii* develops. The myelencephalon is but little altered in its contour.

The otocyst is further differentiated to form the three semicircular canals, their ampullæ, the saccule and utricle, the cochlea, and the ductus endolymphaticus.

SUMMARY OF THE DEVELOPMENT OF THE CENTRAL NERVOUS SYSTEM

The evolution of the central nervous system through the several stages of development may be summarized in five steps:

- I. The *neural plate* gives rise to the *neural folds* which form the *neural tube*.
- II. The neural tube is subdivided into (1) the *encephalon* or brain, and (2) the *myelon* or spinal cord.

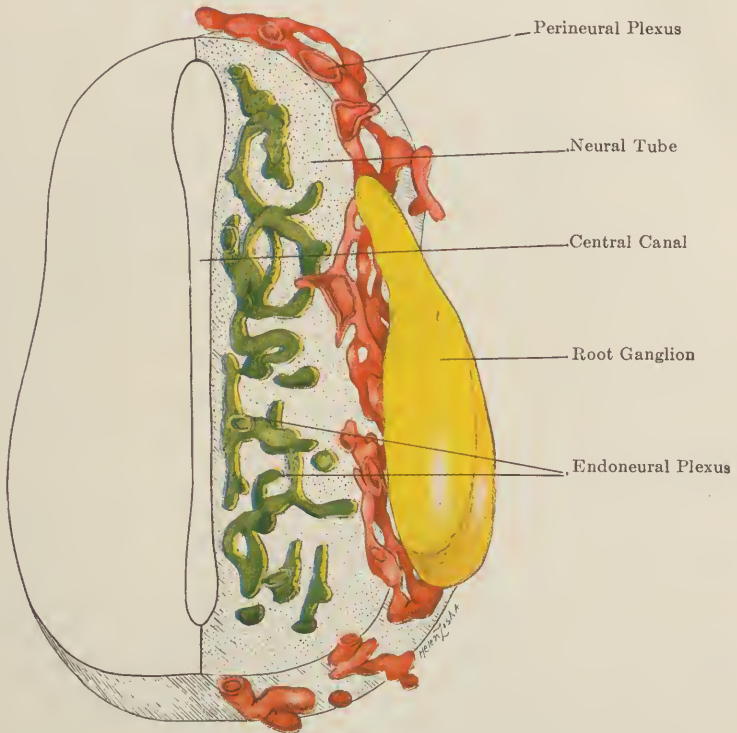


FIG. 41.—Formation of the endoneural and perineural plexus in the 8.5 mm. albino rat.

- III. The encephalon gives rise to three primary vesicles: (1) the *prosencephalon*, (2) the *mesencephalon*, and (3) the *rhombencephalon*.
- IV. From the three primary vesicles, five secondary brain vesicles are derived: (1) from the prosencephalon, the *telencephalon* and *diencephalon*; (2) from the mesencephalon, no further subdivision; (3) from the rhombencephalon, the *metencephalon* and *myelencephalon*.
- V. The adult structures derived from the secondary vesicles are:
 - (1). The telencephalon which gives rise to the *aula* and the *hemispherium*.
 - (2). The diencephalon which gives rise to the thalamus, the subthalamus, the hypothalamus, the epithalamus and the metathalamus.

- (3). The mesencephalon which remains unchanged, forming the midbrain.
- (4). The metencephalon which gives rise to the cerebellum and the pons Varolii.
- (5). The myelencephalon which forms the medulla oblongata.

HISTOGENESIS OF THE NEURAL TUBE

The cellular differentiation which takes place during the development of the central nervous system passes through four phases:

1. The Phase of Differentiation between the Somatic and Neural Ectoderm. During this period of development the ectodermal cells destined to take part in the formation of the nervous system assume an axial position in the embryo and become demarcated from the rest of the ectoderm by an unusually rapid proliferation resulting in an ectodermal stratum four or five cells deep. This thickening gradually tapers off at its lateral edges where it joins the somatic ectoderm at the neuro-somatic junction.

2. The Phase of Development of the Three Cellular Layers in the Neural Tube. These layers, at first not discernible, become distinct when the neural folds have formed the walls of the neural tube. Three layers may then be distinguished:

(a). The innermost or *ependymal layer* consists of germinal and supporting cells which in turn give rise to other cells. These latter move away from the ependymal layer.

(b). The outermost or *marginal layer* consists of the axone processes of the young nerve cells. As growth progresses it develops rapidly in size and comes to form the white matter of the neuraxis.

(c). The intermediate or *mantle layer* consists at first of indifferent cells derived from the germinal layer. These cells subsequently undergo mitosis, giving rise to two types of derivatives, the *spongioblasts* and the *neuroblasts*. The mantle layer increases rapidly in size, during which time, two important differentiations of the next phase take place within it.

3. Phase of Differentiation in the Neuroglia and Ependymal Cells with the Formation of the Internal and External Limiting Membranes. Certain cells from the ependymal layer become differentiated as columnar epithelium possessed of cilia and situated in such a way as to form the lining of the ventricular chambers of the brain. In the adult spinal cord in which the central canal becomes obliterated to a great extent, the ependymal cells are collected in a central mass of large cuboidal elements.

From the spongioblasts in the mantle layer the neuroglial cells are differentiated somewhat later. At first the spongioblasts constitute a primary spongioblastic syncytium. As these cells begin to proliferate, they form a dense meshwork in which appear many spider cells, glia cells and astrocytes. The earlier spongioblastic framework is soon converted into a dense feltwork of cells and fibers whose branches anastomose. This forms a complete supporting structure for the nervous elements of the neu-

raxis. Certain variations in the shape of the neuroglial cells are determined by the nature of the nerve tissue supported by them. In consequence, there are different types of neuroglial cells in the cerebral cortex, in the cerebellum

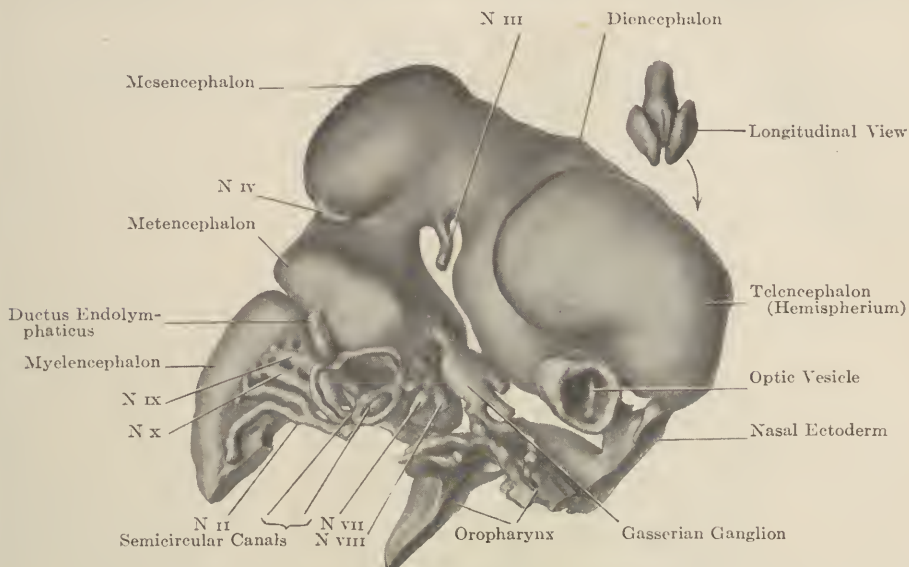


FIG. 42.—Reconstruction showing stage of 17 mm. in *felis domestica*.

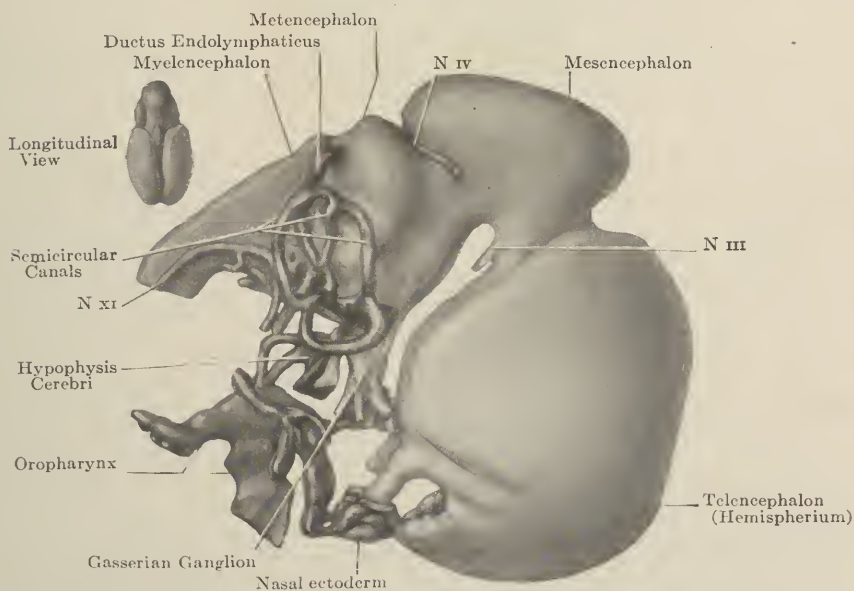


FIG. 43.—Reconstruction showing stage of 26 mm. in *felis domestica*.

and in the white and gray matter of the spinal cord. Neuroglial fibers constitute one-third of the supporting tissue of the central nervous system. They make their appearance late in uterine life and the process of their

differentiation continues even in the adult. Anastomosis of the syncytia, network of these fibers constitutes an *external limiting membrane* which forms the outer neural boundary of the neuraxis. An *internal limiting*

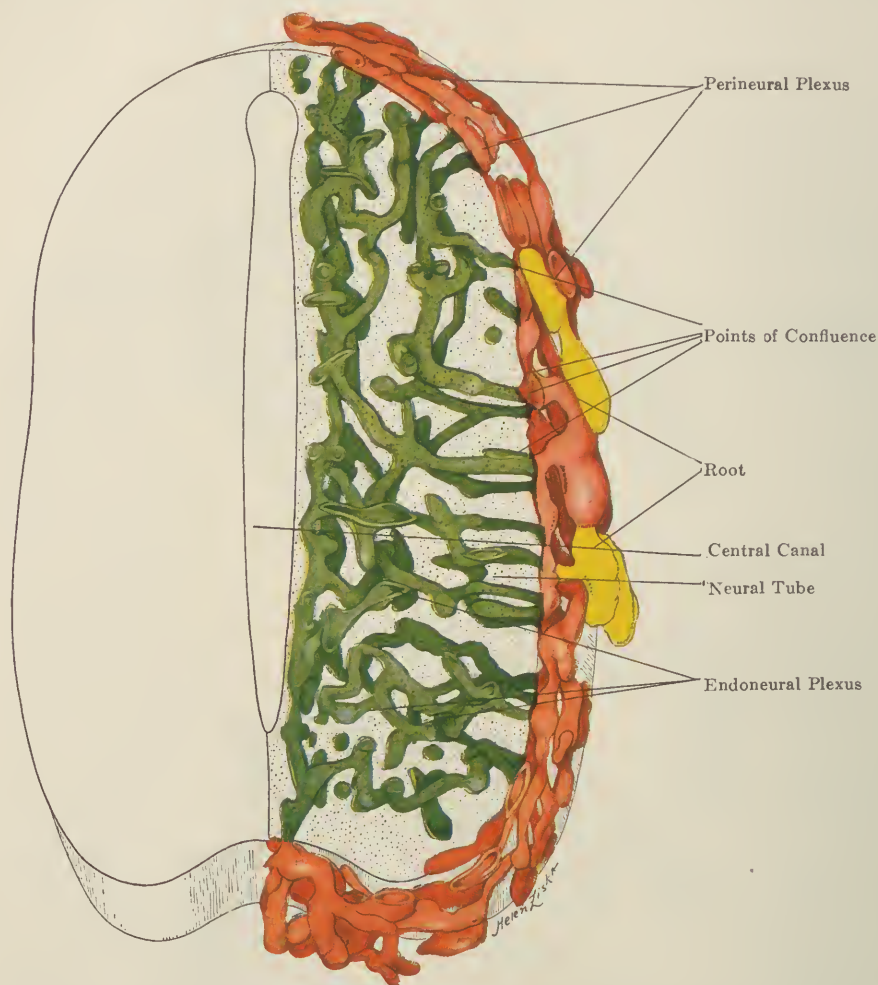


FIG. 44.—Formation of the endoneural and perineural plexus in the 9.5 mm. albino rat showing full confluence of the channels in these two vascular systems.

membrane is similarly formed, thus constituting the inner boundary of the axis.

4. The Phase of Differentiation and Migration of the Neurocytes. The neuroblasts of the mantle layer early begin to show signs of differentiation into the neurocytes. The first sign is the appearance of a long axial process into which the cytoplasm of the cell seems to be drawn, leaving the nucleus at the base of the tapering process. The nucleus is prominent and most of the cytoplasm of the cell is contained in the primary process soon to become the *axone*. Subsequently the original pyriform shape of the neurocyte is altered

by an increase of cytoplasm and the development of secondary cytoplasmic processes which extend into the neighboring spaces. These are the *dendrites*. The neurocyte at this period possesses a nucleus, a soma or body, an axone,

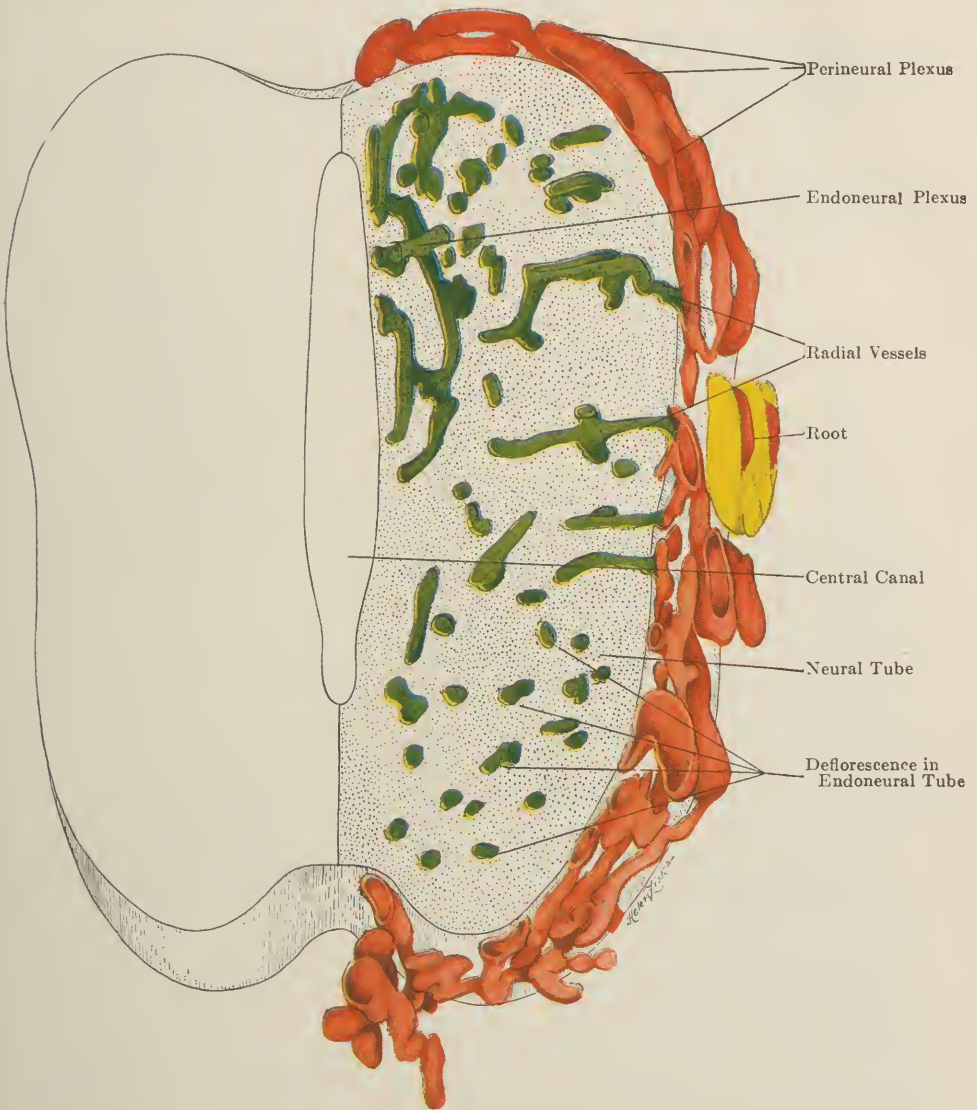


FIG. 45.—Formation of endoneurial and perineurial plexus in the 11 mm. albino rat, showing the deflorescence in the systems of channels and development of the radicular vessels of the central axis.

and dendritic processes. The development of the *neurofibrils* within the substance of the cell body and its processes occurs simultaneously with the differentiation of these parts of the nerve cell. Even before this ultimate differentiation has taken place, the neuroblasts show a tendency toward migra-

tion. Those cells developing in connection with the basal plate move into a ventral position where their collected mass constitutes the gray matter entering into the formation of the ventral gray column of the spinal cord and the homologous gray masses of the brain-stem. When these cells have mi-



FIG. 46.—Dorsal cord of chick embryo at 5th day of incubation. (Cajal.)

A, B—Motor cells. C—Ventral roots. D—Dorsal roots. E—Dorsal columns. a—Superficial white substance. b—Commissural fibers.

grated into this ventral position, their axones begin to traverse the mantle layer, penetrate the marginal layer, and finally emerge from the neuraxis as the *ventral roots*.

A still greater degree of migration is seen in the cells which form the alar plate. This migration gives rise not only to the dorsal gray column of the spinal cord and homologous areas in the brain-stem, but some of these neuroblasts proceed still further to form the neural crest. In this structure differentiation is carried on by which some of the neurocytes become *sympathicoblasts* and others *ganglioblasts*. The sympathicoblasts in their turn undergo further migration, leaving the neural crest to form the *prevertebral*



FIG. 47.—Epithelium of the cord in chick embryo at 5th day of incubation. Golgi's method. (Cajal.)

A—Epithelial flask. B—Epithelium of the dorsal groove. C—Branched fibers in the ventral column. *ganglia* of the ganglionated cord of the sympathetic system. The gangliocytes of the neural crest become differentiated to form the *dorsal root ganglia* of the cerebrospinal nerves. In this process the neuroblasts pass into the neurocyte stage by a marked increase in their cytoplasm. Their nucleus is retained in the center of the cell. The soma gives off a central and a peripheral branch. These later join and produce the adult unipolar bifurcated arrangement. The neurofibrils appear in the cytoplasm of the cell simultaneously with the appearance of the processes. In this manner the sensory elements of the peripheral nerves and dorsal root fibers are differentiated.



FIG. 48.—Sketch of the motor roots in the lumbar cord in an embryo of a duck at the 70th hour of incubation. Silver nitrate reduction. (Cajal.)

A—Spinal cord. B—Perimedullary space. C—Meningeal membrane. D—Cone of growth of motor nerve fiber. E, F—Cones in perimedullary space. G—Cone migrating toward the dorsal region. a, b—Stationary cones. c, d—Cones travelling in the antero-posterior direction under the basal membrane. e—Motor nerve fiber.

CHAPTER IV

THE UNIT OF STRUCTURE OF THE NERVOUS SYSTEM

THE NERVE CELL OR NEURONE

Adaptation to the Purposes of Generating and Conducting Nerve Impulses. The manner in which a mechanism operates to accomplish its purposes depends upon the constituents which enter into its structure. The operations of the nervous system are made possible by the presence of two distinct substances, one, the *white matter*, which is comprised of nerve fibers, the other, the *gray matter*, made up of nerve cells. In a general sense the white matter plays the relatively passive part in the conduction of nerve impulses, while the gray matter is much more actively engaged in the generation or transmission of these impulses. There is a third element in the nervous system, the *neuroglia*, which serves as a supporting and protective substance.

Although the gray and white substances appear to be different in kind, they are in fact part of the same essential tissue constituting the nervous system. The gray matter is made up of the bodies of cells whose conducting processes, the axones, constitute the white matter. From this fact it is apparent that the unit of structure of the nervous system is the nerve cell or *neurone*, in which two main divisions may be distinguished, the *cell body* or *soma*, and the *cell processes*.

Certain features of the nerve cell cause it to stand out among the other cells in the organism. Before considering its form and characteristics, however, it will be advantageous to view the neurone as a living organ, taking into account its purposes and the manner in which it achieves its ends.

As a living organ, the nerve cell carries on the complex chemical activities involved in its metabolic processes and designed to regulate the assimilation of nutritive material brought to it by the circulation. In a word, the neurone has its chemical problems to meet and is equipped with the proper mechanism for this purpose.

Nerve cells are constantly generating, receiving or storing up nerve impulses. It is unfortunate that we do not know the exact character of such impulses. Whether they are chemical or electrical or a combination of both, is a question which has not yet been definitely answered. In a few isolated instances, it is known that they are electrical in their nature. Such, for example, are the impulses generated by the electric organ in the medulla of the *electric torpedo*.

Another function of the nerve cell is the delivery or transmission of impulses which it generates, receives or stores up. This cellular activity requires the existence of a special apparatus.

STRUCTURE OF THE NEURONE

In view of these facts it may be assumed that the nerve cell not only presents many of the characteristic structures of other cells in the body, but is also provided with special mechanisms for the performance of its own special functions.

The Cell Membrane. In the first place, to set it apart from all other elements as a living organism the nerve cell is possessed of an essential membrane, in which respect it resembles other cells. This membrane limits

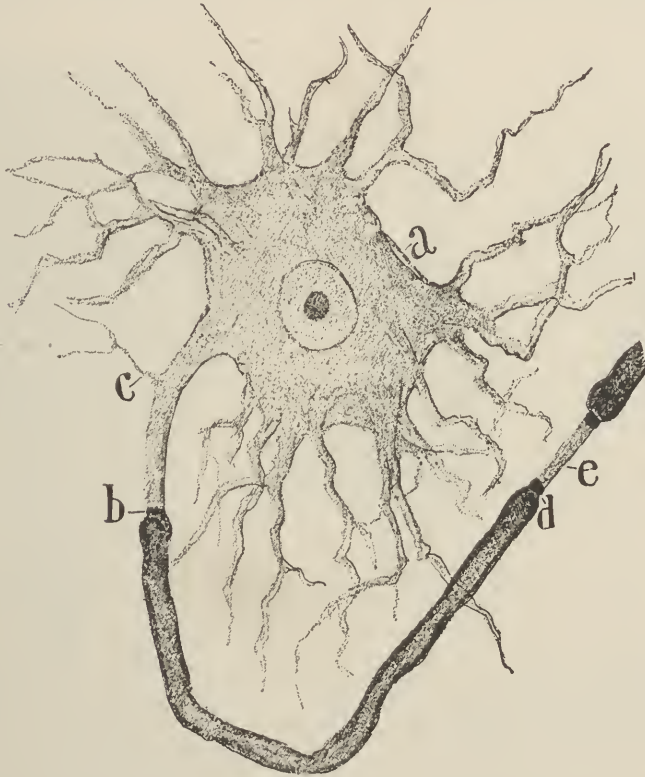


FIG. 49.—Cell of the cerebro-electric lobe of the torpedo. (Cajal.)

a—Membrane, slightly separated from the protoplasm. *b*—Connecting link. *c*—Collateral nerve branch. *d*—Disc of union or link in the constriction of Ranvier. *e*—Constricted region of axone unprovided with myelin.

the cytoplasm and seems to be a peripheral condensation of the protoplasm which serves to contain the cellular elements. The membrane is often more complex than a mere peripheral concentration of cytoplasm; it may be converted into an actual endothelio-conjunctival capsule. This is the case in the essential membrane of the dorsal root ganglion and sympathetic cells. The cell in the electric organ of the medulla oblongata in *torpedo* shows the same kind of highly specialized limiting membrane, which probably serves as an insulation from adjacent cells in the electric lobe. Peculiar pericellular

nets have been identified in the cell membrane, concerning the nature and significance of which different views have been expressed. These pericellular nets have been considered essential for the conduction of impulses from cell to cell. Provision for this function, however, seems to be made in a more ample and better way. According to Cajal, the nets represent focal regions of greater density and concentration in the periphery of the cytoplasm constituting the essential membrane.

The Cytoplasm. The second element in the nerve cell is its cytoplasm, that is, all of its protoplasm except that filling the nucleus. This cell plasm is made up of a fibrillar network called the *spongioplasm* or *achromatic net*. It lodges a chromatic or deeply staining substance and is distributed through-

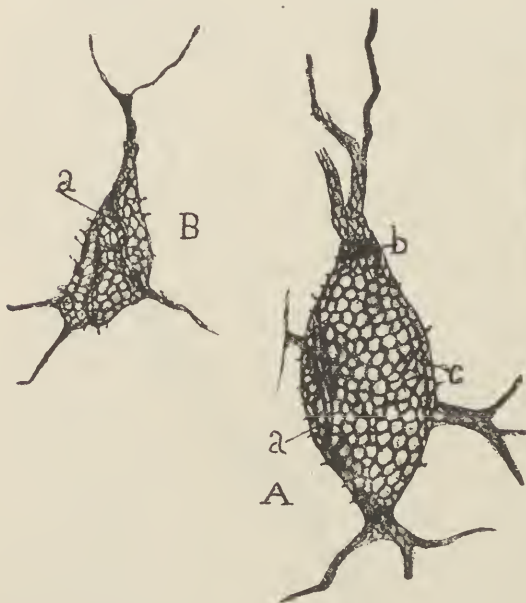


FIG. 50.—Short axis cylinder cells of the brain; adult cat. Ehrlich's method. (Cajal.)

a—Pericellular network. c—Spiny processes. b—Condensation of network at dendritic origin.

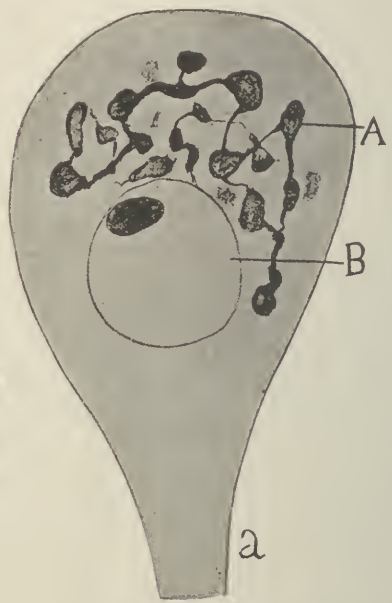


FIG. 51.—Cell of the ganglionated chain of the earth worm. Silver nitrate reduction. (Cajal.)

A—Intraprotoplasmic canals of Holmgren-Golgi. B—Nucleus. a—Protoplasmic process.

out the entire cell, including the single, most highly specialized process, the *implantation cone*. In the meshes of this network is the cytoplasmic fluid or *hyaloplasm* which serves as the medium of chemical exchange in the cell, while the spongioplasm serves as a delicate, internal scaffolding.

Intracytoplasmic Canals. Another important set of organs in the neurone are the *Holmgren-Golgi canals*, which form a complex apparatus throughout the cytoplasm. These canals are brought out by means of silver impregnation and present the appearance of an actual net. They are regarded by some authorities as intracytoplasmic lymph channels which are in connection with pericellular lymph spaces surrounding the neurone. The canals are not peculiar to nerve cells but have a wide distribution among

the cells of the body, in vertebrates as well as in invertebrates. In the cells of the intestinal tract of the earthworm, these canals are found immediately beneath the limiting membrane. In vertebrates, their relation is usually circumnuclear, that is, surrounding the nucleus and extending according to some authorities, to the periphery by means of minute branches which connect with the pericellular lymph spaces.

These three parts of the nerve cell provide the support for its structure, the medium of exchange for its metabolism, and it may be, the circulatory apparatus for its nutrition.

Chromophilic Substances—Nissl's Bodies. Another feature of the cytoplasm of the neurone is the *chromophilic substance* or *granules*. These

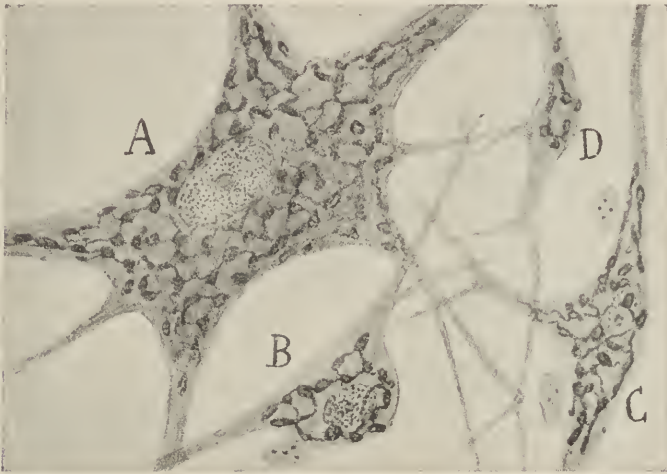


FIG. 52.—Intraprotoplasmic tubular network in the different nerve cells of the spinal cord of a dog, eight days old. Reduced by silver nitrate method. (Cajal.)

A—Large funicular cell. B, C, D—Small funicular cells.

granules stain with basic anilin dyes and are known as *Nissl's bodies* or *tigroid bodies*. They vary considerably in form and dimensions, some being irregular masses, others spherical or ovoid. In size they measure from 1 to 10 micra. The arrangement and disposition of the chromophilic granules vary in different cells according to their functional activities. It is possible by this criterion to recognize the functional type to which a cell belongs. Nerve cells are classified in several ways, but one of the most significant is that based upon the disposition of the chromophilic granules. Four different types of neurones are thus distinguished: (1) The *stichochromes*; (2) the *arkyochromes*; (3) the *gryochromes*, and (4) the *perichromes*.

The principal feature of the *stichochrome cells* is the irregular form of their Nissl's bodies, which are arranged more or less evenly in rows. They vary in size from 1 to 4 micra, and are found scattered throughout the cytoplasm of the soma, of the bifurcation cones and of the dendrites. Stichochrome cells almost invariably have a motor function; they appear

in the ventral columns of the spinal cord, in the motor nuclei of the bulb, pons and midbrain, in Deiters' nucleus, in the Betz cells of the motor cortex, and the cells of Purkinje in the cerebellum. Upon histological examination, Nissl's bodies of these cells appear to be non-homogeneous.

In the *arkyochrome cells*, Nissl's bodies are arranged in a network. The best illustration of this type of nerve cell is found in the central cochlear nucleus.

The *gryochrome cells* present no specific arrangement of Nissl's bodies, which are scattered throughout the cytoplasm in an irregular manner.

This variety is typified by the cells in the spinal ganglia and in the root ganglia of the cranial nerves.

In the *perichrome cells*, Nissl's bodies are arranged in rows immediately beneath the cell membrane. Such cells are found in the ganglion habenulæ, in the molecular layer of the cerebellum and in the substantia gelatinosa of Rolando.

The functional significance of Nissl's bodies is still open to discussion. These elements are considered by Rosén as similar to the metaplastic inclusions in leucocytes. Van Gehuchten regards them as a nutritional reserve store, while Marchi held the opinion that they represent the *energypiasm* or *kinetoplasm* of the cell.

Other Cell Pigments. Fuchsinophile granules are found in many cells, and particularly in the larger nerve cells. Although the significance of these particles is not fully understood, they are

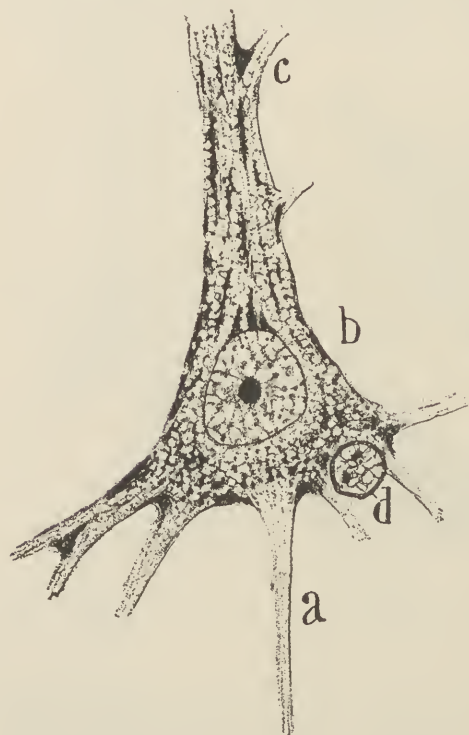


FIG. 53.—Giant pyramidal cell of the human brain. (Cajal.)

a—Axone. b—Cell body. c—Bifurcation cone. d—Nucleus of neuroglial cell.

believed by many to be closely related to the *bioblasts* of Altmann and the *neurosomes* of Held and hence undoubtedly connected with the metabolism of the cell.

Pigment concretions are found in many large cellular collections throughout the nervous system, which give the tissue a peculiar tinge or coloring. Such are found in the *locus ceruleus* and the *substantia nigra*. Why these localities of the central axis should present a peculiar coloring is not clear, and the subject offers one of the problems concerning the life history of the nerve cell which is still to be solved. Many normal nerve cells contain small accumulations of fat, or fat-pigment, *lipochrome*.

The Neurofibrils. Another set of structures in nerve cells consists of fine filamentous threads which make their way through the cytoplasm in such a manner as to produce a complex reticulum, the *neurofibrillar network*. This network, composed of fine neurofibrils, seems to be possessed of an anatomic as well as a functional polarity. The fibrils enter the soma by means of its dendritic processes and converge toward the axone. They do not ramify or anastomose, but become a fasciculus as they approach the axone-hill. This arrangement would seem to imply that the neurofibrils

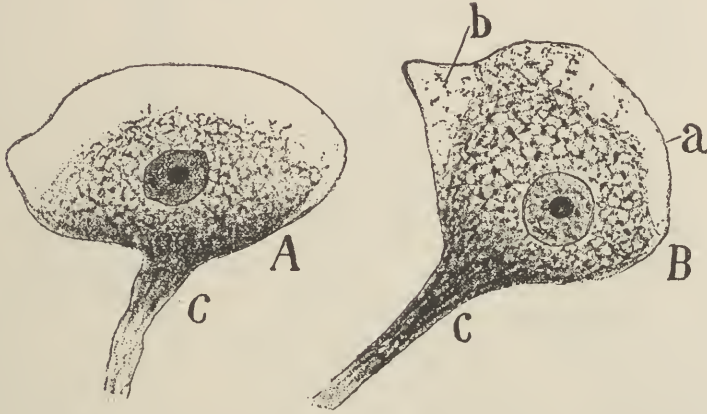


FIG. 54.—Cells of the ventral or anterior acoustic nucleus. Complete alcohol fixation and coloration by Nissl's method. (Cajal.)

a—Membrane separated from the protoplasm. b—Isolated trabecule of the spongioplasm. c—dendritic process in which the protoplasmic chromatin is accumulated.

are collected from all the outlying protoplasmic portions of the neurone and concentrated upon the axone through which they leave the cell.

The nerve cell is possessed of a *dynamic polarity* in consequence of which impulses enter it at one pole and leave it at the other. Since the neurofibrils follow the lines of this polarity it may be presumed that they serve to collect the impulses coming into the cell, to conduct them through its substance and finally to deliver them for transmission to the axone. In this light the neurofibrils are structures which collectively constitute the *organ of conduction through the neurone*.

Apathy, who first discovered the neurofibrillar network in the nerve cells of invertebrates, believed they represented a means of direct communication from one cell to the next. In this sense the entire central axis is a syncytium, an uninterrupted conduction medium throughout the brain, the spinal cord and the peripheral portions of the nervous system. Bethe, who first observed the neurofibrils in the nerve cells of man, arrived at similar conclusions. This conception of the nervous system as a direct continuation from one cell to the next by means of the neurofibrils, invalidates the significance of the neurone as the unit of structure of the nervous system. According to this view the soma or body of the cell becomes but an incident

attached to and in connection with the neurofibrils which are the essential conducting medium.

Cajal's extensive studies of the neurofibrils lead him to another opinion. He interprets these elements as integral structures of each nerve cell, never extending beyond the limits of the cell itself. In this sense, the neurofibrils do not serve as the direct connection from one cell to the next, but are the conductors of impulses by means of intercellular contact rather than by cellular continuity. Cajal is also of the opinion that the neurofibrillar nets are much more complex than either Bethe or Apathy regarded them. He was able to distinguish certain types of cells according to the arrangement of their networks.

The first variety is the fixed form in which the neurofibrils are arranged

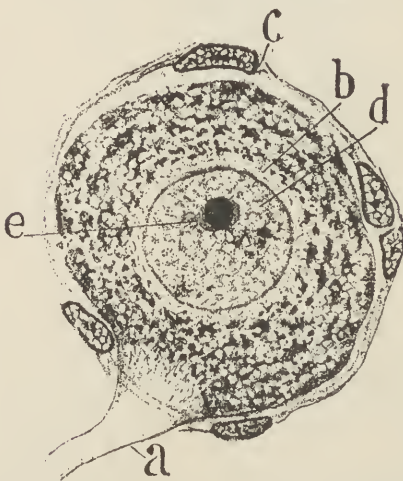


FIG. 55.—Unipolar cell of a spinal ganglion of a rabbit. Sublimate fixation. Nissl's stain. (Cajal.)

a—Axone. b—Perinuclear zone with few chromatin masses. c—Capsule. d—Linin network of the nucleus. e—Perinucleolar masses of basic material or masses of Levi. The protoplasm of the cell is sprinkled with irregular chromatin masses.

in three layers: (1) The superficial and plexiform layer immediately beneath the cell membrane; (2) the perinuclear layer, surrounding the nucleus with a plexiform arrangement of neurofibrils; (3) the layer occupying the intervening substance of the cytoplasm and known as the principal layer.

The second type of nerve cell is characterized by a reticular formation of its neurofibrils, while the third type, more complex than either of the others, combines these two forms and presents a reticulo-plexiform arrangement in the network. That the collected mass of the neurofibrils in the nerve cell constitutes a conducting organ is strongly advocated by Cajal, although he emphatically denies the continuation of the neurofibrillar network from one cell to another.

The Nucleus. Another element typical of all cells is also found in the neurone, the *karyoplasm* or *nucleus*. The nucleus of the nerve cell is usually situated at or near its center, is spherical in form, and varies in size from 14 to 16 micra. It has a nuclear membrane, a chromatin network, an achromatic substance, one or two nucleoli, an accessory body, and a linin network. It differs but little from the nucleus of the typical cell and represents the vital center of the metabolic processes.

Absence of the Centrosome. An important element of the typical cell is missing in most neurones—the *centrosome*. This organ is not present in the neurones of most vertebrates. It has been observed only in the nerve cells of the frog. Its absence is of much significance, since the centrosome is to be regarded as the initiator of cell division. The lack of such an organ

would indicate the loss of the reproductive potentiality on the part of the cell. The majority of somatic cells are possessed of a certain degree of repro-

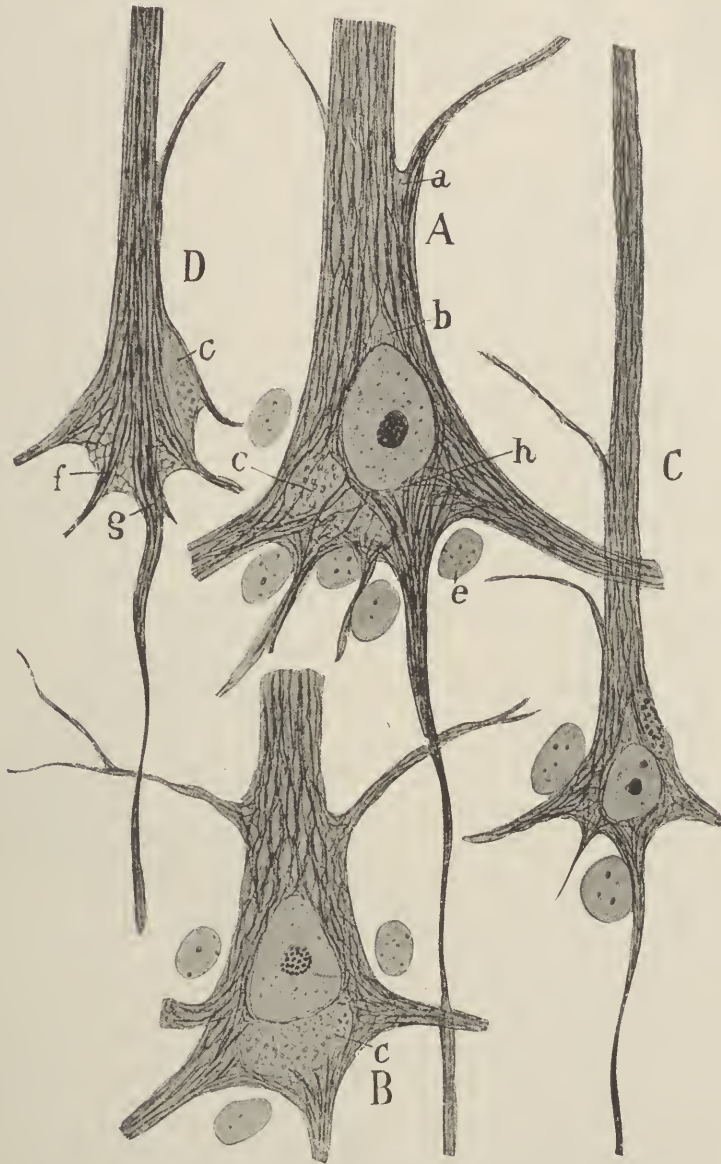


FIG. 56.—Giant pyramidal cells or cells of Betz in the human brain. Reduced by the nitrate of silver method. (Cajal.)

a, b—Spaces corresponding to the chromatic areas of Nissl. *c*—Collections of pigment. *e*—Nucleus of neuroglial cell. *f, h*—Neurofibrils entering into the axis cylinder. *g*—Axis cylinder. *A, B, C, D*—Pyramidal cells.

ductive power; but the nerve cell, probably because of its high degree of differentiation, seems to have lost this important capacity. Clinically, this

characteristic of the neurone is of the utmost importance, since it indicates that a process of repair by reproduction in the central nervous system is not possible.

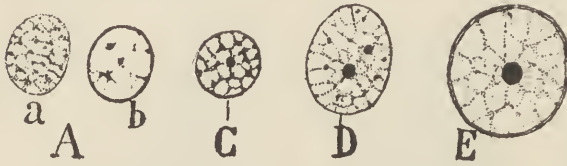


FIG. 57.—Different types of nuclei in nerve and neuroglial cells of a rabbit. Nissl's method. (Cajal.)

A—Two aspects of the nucleus of the neuroglial cells. *a*—Showing the superior surface of the nucleus. *b*—Showing its cross section. C—Nucleus of a granule cell of the cerebellum. D—Nucleus of a pyramidal cell of the brain. E—Nucleus of a motor cell of the cord.

Many of the organs of a nerve cell are much the same as those found in typical cells elsewhere in the body; indeed, if it had no further specialization than the features already noted, it would be difficult for the neurone to carry on its functions. It re-

mains to be seen in what details the nerve cell differs from the typical cell in order that it may fill its special offices.

Form of the Nerve Cell. In form, the neurone is highly specialized. It may be pyramidal, pyriform, globular, stellate or fusiform. It differs from typical cells in that three different parts may be recognized in it. These are: (1) the *soma* or the cell body; (2) the *dendrites* or *protoplasmic processes*; (3) the *axone* or *neurofibrillar process*. These parts, either in their usual appearance or in some modification of it, are characteristic of all nerve cells. The soma varies much in size and form. Its constituents have already been described, as well as its types, according to its different functions.

The Dendrites. The dendrites are the protoplasmic processes of the cell. They form a series of more or less thick branches which extend out

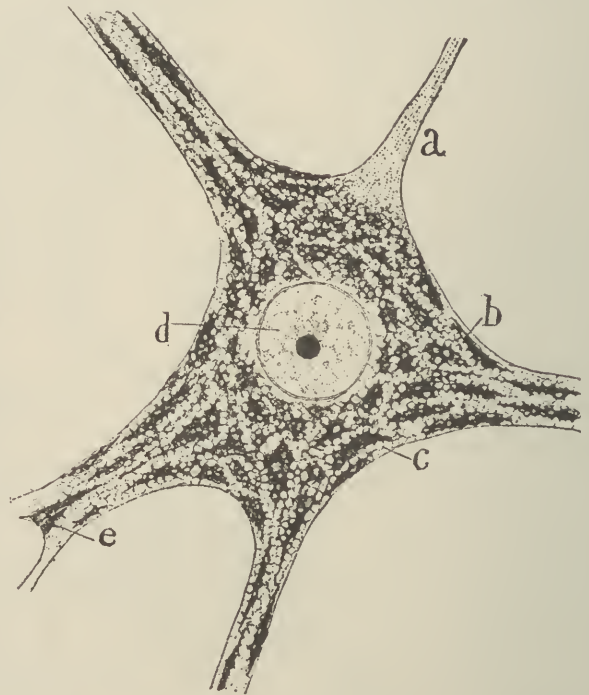


FIG. 58.—Motor cell of the spinal cord of a rabbit. Nissl's method. (Cajal.)

a—Axis cylinder. *b*—Chromatic mass. *c*—Spongoplasm. *d*—Nucleus. *e*—Bifurcation cone.

from the soma. The dendrite has a trunk and an end-arborization. The trunk divides dichotomously until its branching has given rise to a dense end-brush. Each dendrite has upon its branches a number of minute *globular dodies*, known as *gemmules*, *spines* or *varicosities*. They are regarded by some

observers as artifacts, but the majority of authorities consider them the contact points in the synaptic junction between one cell and another. The trunk of the dendrite tapers slightly as it passes away from the soma. The number of dendrites connected with each cell varies from one to ten. The dendrites may be identified by their relatively large size. The axone is the slender process of the cell and may extend a great distance from its body, while the dendrites never pass outside of the gray matter. All synaptic junctions for this reason are located in the gray substance. The constituents of the dendrite are the same as those of the soma, that is to say, cytoplasm, spongioplasm and hyaloplasm, the chromophilic substance, the tubular apparatus of Holmgren-Golgi and the neurofibrillar network. In the larger branches and trunk of each dendrite Nissl's bodies are prominent elements. At the point of bifurcation of the trunk into the first branches, there is usually a large Nissl body marking what is known as the *bifurcation cone*. In the smaller dendritic branches, Nissl's bodies become progressively less in size and have the appearance of fine chromophilic flecks scattered throughout the protoplasmic substance.

The Axone. An important distinguishing characteristic of the nerve cell is its axone. This, unlike the dendrites which are protoplasmic, is distinctly a neurofibrillar process, and in reality contains but few of the elements constituting the cytoplasm of the soma. In contrast to the dendrites which are *somatipetal*, the axone, in regard to the impulses which it conducts, is *somatifugal*. It is to be identified by its form, size, relations and constituents.

The axone through most of its course is a cylindrical tube. Certain portions of it, however, may not be described as tubular and these exceptions will be mentioned later. In length the axone varies from a few millimeters to many centimeters. Short axones are found in cells whose somatifugal process never leaves the gray matter. These are known as cells of *Golgi type II*. Cells with long axones often send their somatifugal process through a distance extending from the Betz cells of the motor cortex of the brain to the lumbar region of the spinal cord. Those cells which send their axones through

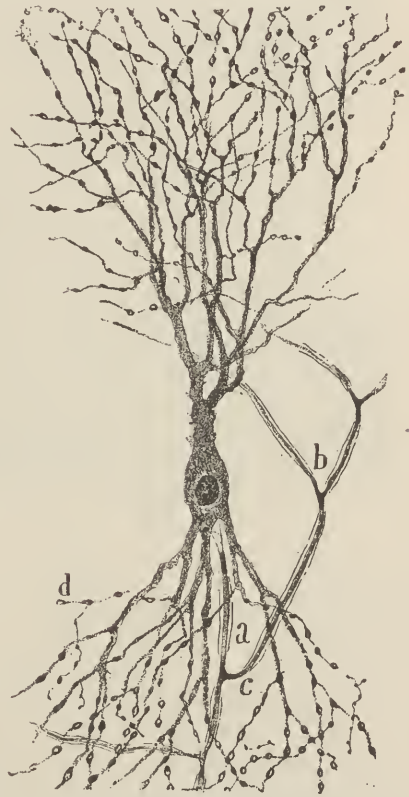


FIG. 59.—Giant cell of the inferior part of the cornu ammonis of a rabbit. Method of Ehrlich-Bethe. (Cajal.)

a—Axis-cylinder. c—Collateral dividing into further branches. d—Varicosities of the dendritic enlargements.

the white substance of the central nervous system or into the peripheral nerves are known as cells of *Golgi type I*. The transverse diameters of axones differ according to the amount of myelin sheath which has been secreted as a tubular investment upon the neurofibrils. A cross section of the spinal cord will show the axone as a central rod made up of compact neurofibrils surrounded by a lighter, homogeneous encasement, the *myelin sheath*.



FIG. 60.—Purkinje cell of the human brain. Golgi's method. (Cajal.)

a—Axis cylinder. b—Collateral branch. c, d—Spaces among the protoplasmic branches for the stellate cells.

The axonal divisions distinguish the axone from the dendritic processes. First among these divisions is the *implantation cone* or *axone hill*, through which the neurofibrils pass to enter the axone. This appears as a specialized portion of the soma and is distinguished by the fact that the cytoplasm here is devoid of Nissl's bodies. Differentiation between the trunks of dendrites and the beginning of the axone is easily made by this means. At the base of the implantation cone and extending for some distance into the cytoplasm of the soma, all chromophilic elements are drawn inward and the plasma has a clear homogeneous appearance. The axone hill is usually shorter than the dendritic trunk, and as it proceeds away

from the cell body it gradually tapers.

At the apex of the cone, the cytoplasmic substance of the cell disappears and the axone is here nothing more than a fascicular collection of the neurofibrils surrounded by periaxonal substance. This, the second division of the axone, characterized by the absence of protoplasmic covering, is known as the *axone cervix* or *neck*. Its length is variable and depends upon the position of the nerve cell from which the axone arises. If this cell is situated deep in the gray matter the axone cervix may be long. As a rule the axone arises directly from the cell body in what may be called the *axonal pole*. There are, however, certain exceptions to this rule, as in the case of some of the *granule cells* in the *granular layer* of the cerebellar

cortex in which the axone may take origin from one of the dendritic processes.

The third division of the axone is identified by the fact that it has acquired an outer covering, the myelin sheath, which is regarded as a secretion of the neuroglial cells. This sheath is maintained from the point of its first acquisition by the neurofibrils until they approach their end-

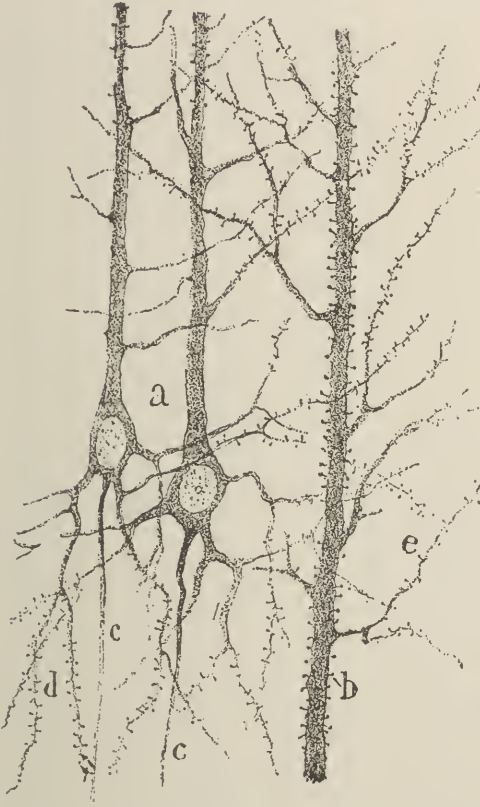


FIG. 61.—Pyramidal cells of the cerebral cortex of a guinea-pig, showing the spines of the protoplasmic processes. Ehrlich's method of methylin blue. (Cajal.)

a—Two medium pyramidal cells. *b*—Collateral spines of a protoplasmic trunk belonging to a giant pyramidal cell. *c*—Axis cylinders. *d*—Basilar branches with their spines. *e*—Collateral branches of the protoplasmic trunk with their spines.

The fourth division of the axone is represented by its branches. These are of two classes; the *collaterals*, which are generally given off at right angles to the course of the axone, and the end-branches, which are devoid of the myelin sheath, since this covering disappears at the point where the axone begins to break up into its *end-arborization*. The end-branches are studded with many fine gemmules or varicosities in the same way as are the branches of the dendrites. They are not all of the same character, but vary consider-



FIG. 62.—Details of the spines on the protoplasmic processes of the Purkinje cells. Ehrlich's method. (Cajal.)

A—Dendrite with gemmules. *B*—High power of same. *a*—Dendrite.

arborization. After the axone has received its myelin sheath, it is known as the *axis cylinder* of the nerve fiber.



FIG. 63.—End-baskets of Held enveloping the cells of the nucleus of the trapezoid body in an adult cat. (Cajal.)

a—Vacuoles. *b*—Terminal fiber.

ably in form. In many instances rich end-arborizations may be observed in profuse branchings of the neurofibrils. Another type is found in the *end-baskets of Held*, and still other types are the *terminal buttons* and *terminal end-nets*.

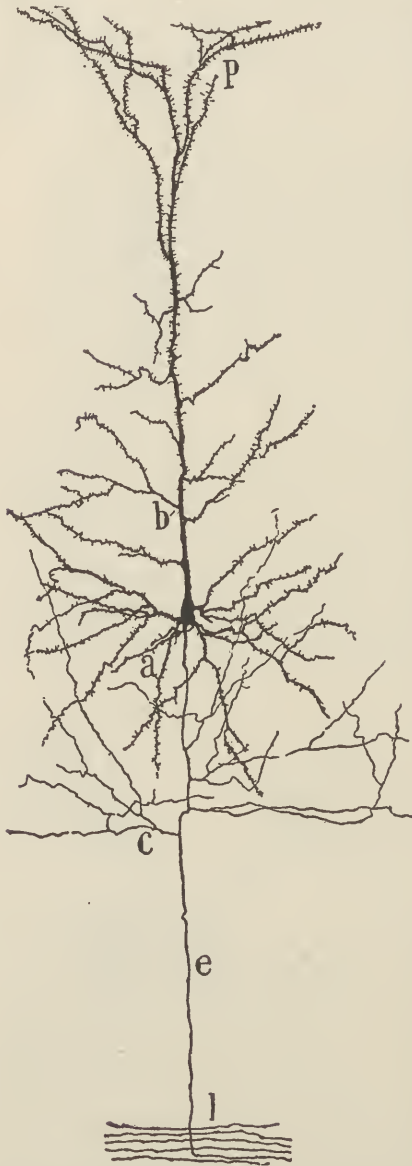


FIG. 64.—Pyramidal cell of the brain of a rabbit. Golgi's method. (Cajal.)

a—Basilar protoplasmic branches. b—Dendritic trunk and its branches. c—Collaterals of axis-cylinder. e—Long axis cylinder. l—The white matter. P—Dendritic arborization.

The axone varies in its constituents throughout its several divisions. Its fundamental elements are the neurofibrils, and these may be found from one end of the axone to the other. The implantation cone or axone hill is made up of these neurofibrils surrounded by the cytoplasm of the cell in which, however, there are no masses of chromophilic substance. The axone cervix consists of neurofibrils, together with a very small amount of perifibrillar substance which surrounds the fibrils. The nerve fiber consists of a central core of neurofibrils, its accompanying perifibrillar substance and a myelin sheath which is a lipoid or albumino-adipose substance; thought by many to be secreted by the neuroglial cells. This is true of the nerve fiber as it is found in the central nervous system, but in the peripheral nerves the tubular sheath surrounding the neurofibrils contains other structures which will be described in the discussion of the peripheral nerves. At more or less irregular intervals along the course of the axis cylinders as they make their way through the white matter of the central nervous system, there occur certain nodular bodies known as the *nodes of Toureux-Legraff*. These are most common at the point of axone bifurcation, and differ from the nodes of Ranvier in the peripheral nerves in that, according to Cajal, they possess two discs instead of one.

The existence of a neurilemma, or sheath of Schwann, such as has been described in connection with the peripheral nerves, has been denied in the axis cylinders of the central nervous system. It may, however, exist as an

extremely fine outer covering of the myelin sheath. The incisures of Schmidt-Lantermann, such characteristic features of the peripheral nerves, are not encountered in the axis cylinders of the central nervous system.

THE NEUROGLIA

Derived from the ectoderm, as are the neurocytes, a second type of cell is found in the central nervous system. This is the neuroglia which forms a supporting and protective tissue. The neuroglia is made up of cells having the general characteristics of other cells in the body. Such cells present a cytoplasm containing fine granulations irregularly distributed throughout the body of the cell and extending into the proximal portions of the principal appendages. A second element is represented by a large number of radiating fibers connected with the cell and extending in all directions from it. Each neuroglial cell has a relatively large nucleus limited by a well-defined achromatic membrane; it contains chromatin particles and one or two nucleoli. A small body situated in the cytoplasm is generally regarded as the centrosome. The neuroglial cell, being less highly differentiated than the nerve cell, seems to retain a potentiality common to most somatic cells, in that it is able to reproduce itself.

Types of Neuroglia. There are two principal varieties of neuroglial cells, those situated in the white matter and those in the gray matter. The neuroglial cells of the white matter are characterized by their long fibers. The cell body is 6 to 11 micra in diameter and is in connection with twenty to forty fiber prolongations. Not all of these prolongations are of the same size or character. In general, the fibers of the neuroglia in the white matter may be classed in three groups:

1. Filaments of a moderate fineness and relatively short.
2. Filaments which are fine but extend for a great distance away from the cell body.
3. The so-called vascular appendages of the neuroglial cells which are comparatively thick filaments with clubbed ends, the latter adhering to the endothelium of the capillary vessels in the neighborhood of the cell.

The neuroglial fibers of the white matter form more or less complete envelopes for the axis cylinders and the blood vessels, *membrana limitans gliae perivascularis*, while at their distal extremities, they become confluent one with another and in this way form a reticular limiting membrane around the outer surface of the neuraxis, the *subpial neuroglial membrane*, *membrana limitans gliae superficialis*.

The neuroglial cells in the gray matter differ from those in the white matter chiefly in that their fiber processes are shorter, more branching and give the whole cell a mossy appearance. Several varieties of the neuroglial cell are recognized in the gray matter:

1. *Perivascular Cells.* These elements have a triangular or irregular body, the surface of which is in contact with a capillary, in this way reinforcing the capillary wall.

2. *Pediculated Cells*. This form of neuroglia possesses a short or long pedicle which is simple or branched and which by its extremity is implanted upon the wall of a capillary, or the external limiting glial membrane or the superficial limiting glial membrane, having in this regard much the same purpose as the perivascular cell.

3. *Independent Stellate Cells*. This is the most common type; they present a large number of filaments extending from them in all directions. They do not seem to come in contact with blood vessels.

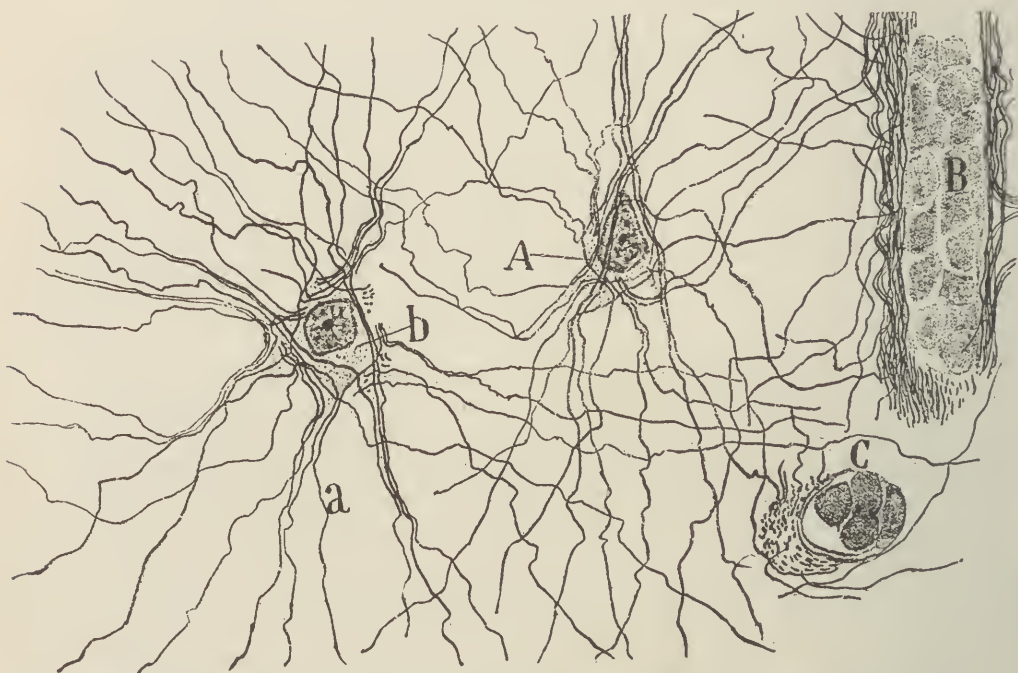


FIG. 65.—Neuroglial cells of the white substance of the human brain. Weigert's method for neuroglia. (Cajal.)

A—Cell body. B—Longitudinal section of a capillary. C—Cross section of another capillary. a—Slender neuroglial fibril. b—Unstained protoplasm.

4. *Caudate Cells*. These neuroglial elements are found in the first layer of the cerebral cortex, and in addition to presenting many branched processes, have several streaming prolongations like the tail of a comet. For this reason they are also sometimes called *cometary cells*. The long, tail-like process extends to the pia mater and in conjunction with similar processes from other neuroglial cells participates in the formation of a *subpial neuroglial limiting membrane*.

5. *Cells with Bifurcated Fibers*. These elements are found in the cortex of the cerebellum and are marked by the absence of any fiber processes except one or two long extensions which usually bifurcate close to the cell and then extend for a long distance from it. Each of these processes is studded with small varicosities and terminates in the outer limit of the cerebellar

cortex, where its extremity is engaged in the formation of a *subpial neuroglial limiting membrane*.

6. *Pericellular Cells*. Neuroglial cells of this type are observed in connection with many of the larger neurocytes throughout the nervous system. The number of such cells surrounding a neurocyte may be three, four or even six, a large number of them usually being found in connection with the pyramidal cells of the motor cortex of the brain. Not infrequently they lie in relation to the beginning of the axone, particularly that part which is free of myelin, the axone neck.

Physiological Significance of the Neuroglia. The physiological significance of the neuroglial cells is not fully understood. Some of their offices are obvious, while others must still be left to the disclosures of further investigation. That the glial cells form an effectual supporting tissue for the nerve elements, a scaffolding for the nerve cells and the axis

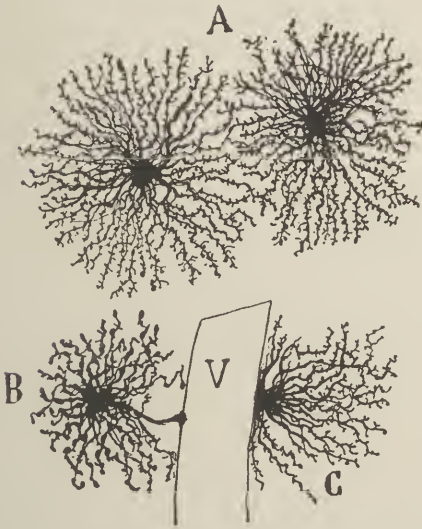


FIG. 66.—Neuroglial cells of the gray substance of an adult human brain. Golgi's method. (Cajal.)

A—Independent cells. B—Cell with vascular pedicle. C—Perivascular cell. V—Capillary vessel.

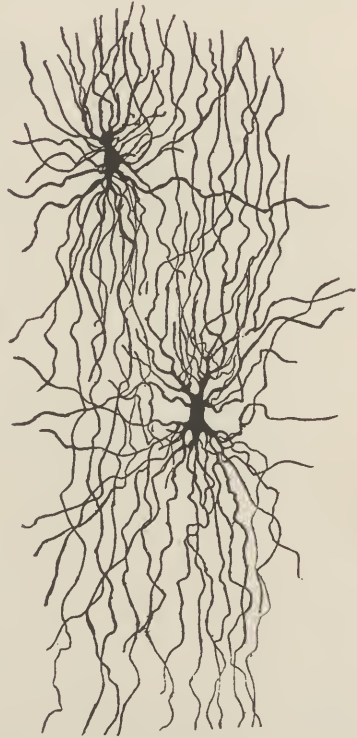


FIG. 67.—Neuroglial cells of the white substance; brain of an adult man. Slow method of Golgi. (Cajal.)

cylinder processes, seems to be without question. By their extensive processes passing to the periphery of the neuraxis, they give rise to a limiting membrane which, although incomplete, none the less effectively provides a reticulated structure covering the surface of the spinal cord and brain. A similar internal limiting membrane is developed in relation with the ventricles of the brain during the developmental stages prior to the disappearance of the central canal in the spinal cord.

The older idea that the neuroglial cells were in some way connected with the processes of providing nutrition for the nerve cells, principally because of their intimate connection with the blood vessels, seems untenable in the light of our present knowledge. It is not possible to explain their existence on the grounds that they serve to fill the wide spaces caused by the expansion of the neuraxis or to obliterate the cavities produced in the neural tissues when the nerve cells undergo a process of degeneration. Many reasons appear to sustain the view that the neuroglia, especially in the gray matter, serves as a tissue element for purposes of insulation, separating one neurone from another and thus preventing undesirable or perhaps harmful contacts between the nerve cells. This interpretation is not applicable, how-

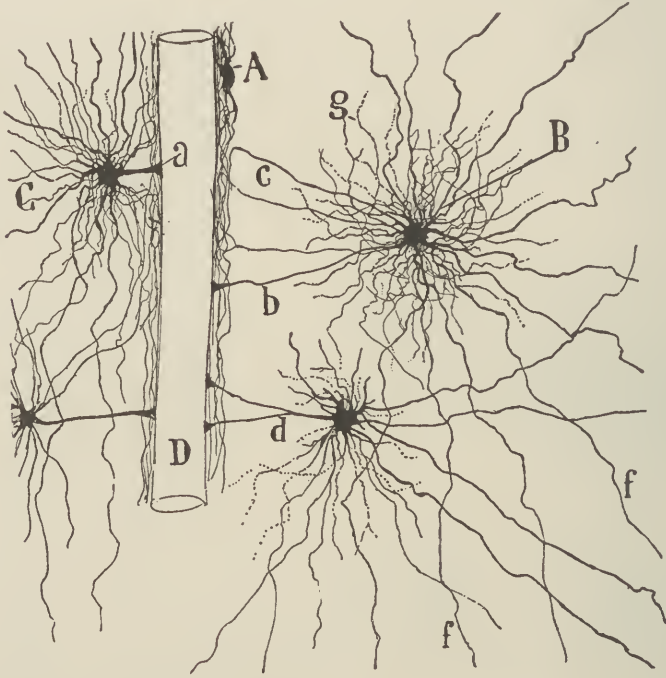


FIG. 68.—Neuroglial cells of the white substance of the brain in an adult man. Slow method of Golgi. (Cajal.)

A—Flattened perivascular neuroglial cell. B—Neuroglial cell with long branches. C—Pediculated neuroglial cells. D—Capillary vessel. a—Pedicle attached to the vascular endothelium. c—Long branches which bend at contact with the vessel to form its perivascular adventitial membrane. d—Bifurcated pedicle. f—Smooth and very long processes. g—Thin and short processes.

ever, to the neuroglia in the white substance. The view advanced by Andreizen concerning these cells has something to recommend it. It is his belief that by virtue of its resistance and elasticity, the neuroglia is able to protect the nerve cells from the vascular pulsations of neighboring vessels.

The marked reaction of the neuroglia against pathological processes going on in the central nervous system, and more particularly those processes which come as a result of toxemia, infection and trauma, must not be overlooked. The rapid proliferation of the neuroglial cells seems to indicate that

they, like certain fixed and wandering tissue cells of the body, are capable of protective response against threatened or actual invasion. This proliferation of neuroglial cells, known as *gliosis*, is so common a manifestation in diseases of the nervous system as to give rise to the belief that neuroglial cells themselves are possessed of a phagocytic power, and that they are capable of creating a barrier for the purpose of limiting the extension of any disease process affecting the brain or spinal cord. In certain inflammatory processes, such for example as acute anterior poliomyelitis, some of the cellular elements engaged in the process of removing the necrotic ventral column cells have been identified as *ameboid glial cells*. In this light the phagocytic activity of at least some of the neuroglial cells cannot be doubted.

PATHOLOGICAL SYNDROMES OF THE NERVE CELL

By syndrome is usually meant a combination of symptoms resulting from some disturbance in the body. In the sense in which this term is applied here it has reference to a combination of pathological changes which may occur in the living nerve cell as the result of some disease. Two major pathological syndromes are recognized in neurocytes, namely, the *syndrome of primary degeneration* and the *syndrome of secondary or Wallerian degeneration*.

1. The Syndrome of Primary Neuronal Degeneration.

The changes in the appearance of the cells are the result of some injurious influence exerted directly and primarily upon the nerve cells themselves. These changes are caused by poisons or by unfavorable physical conditions. They may be occasioned by certain inorganic substances or produced by micro-organisms, such for example as acute anterior poliomyelitis, tetanus and rabies. They may be the result of inanition, of anemia or hyperemia. On the other hand, the determining cause may be physical, such as exposure to extremes of heat and cold.

The most conspicuous change in the nerve cell in primary degeneration is the solution of Nissl's bodies which begin rapidly to break down and

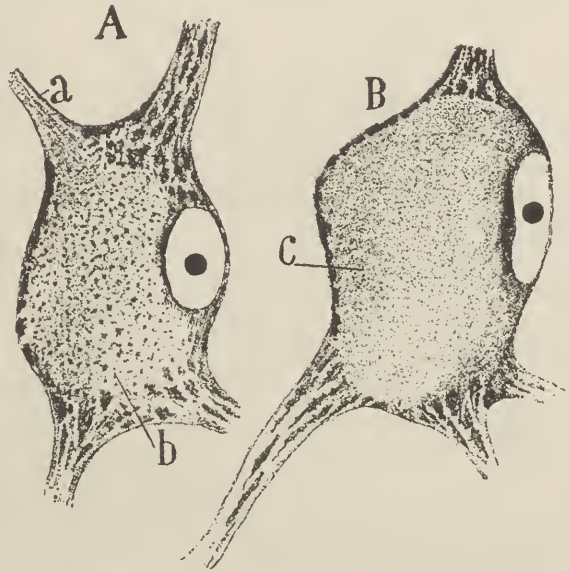


FIG. 69.—Two ventral horn motor cells of the cord of a rabbit in which the large sciatic had been cut fifteen days previously. Nissl's method. (Cajal.)

A—Cells whose chromatin substance is disintegrated and whose nucleus is eccentric. B—Cell in more advanced chromatolysis: a—Axon. b—Small chromatin masses. c—Chromatin dust. The chromatin remains only in the dendrites and in the neighborhood of the nucleus, where it is condensed in a homogenous mass; the cellular membrane is evaginated by the nucleus.

disappear. This process is known as *chromatolysis*. It begins around the periphery of the cell and rapidly extends toward the nucleus. Ultimately all the Nissl bodies disappear, not only from the protoplasmic processes of the cell but from its soma as well.

The second change is seen in a swelling or edema of the cytoplasm of the cell. The cell begins to change its form and finally, on account of the swelling, it becomes more or less globular. The essential membrane appears attenuated as a result of the cellular edema.

The nucleus also becomes swollen and, ceasing to occupy its central position, moves out to the periphery, where it is in contact with the essential membrane, which may ultimately rupture. The nucleus is then extruded from the cell.

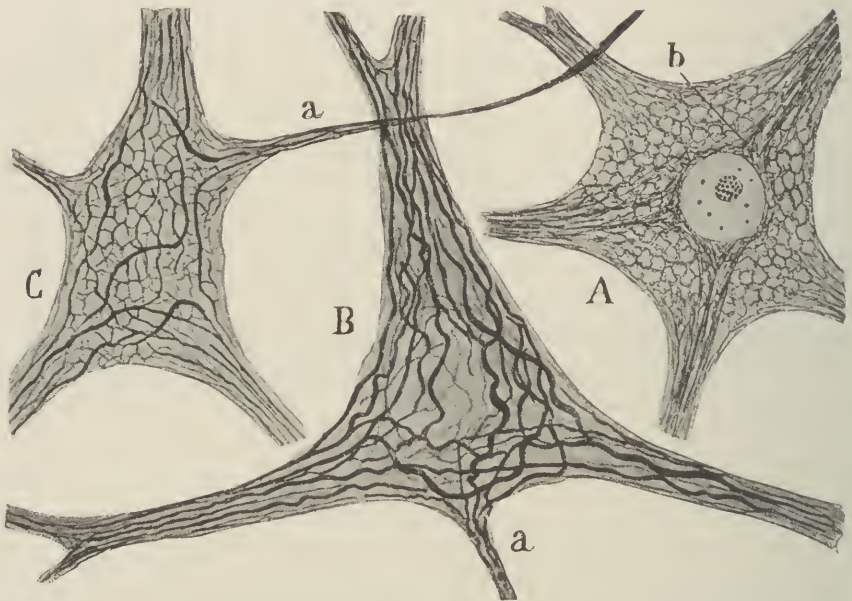


FIG. 70.—Cells of the cord of a rabbit with rabies. Silver nitrate reduction. (Cajal.)

A—Normal cell. B—Neurone where the neurofibrils appear in the form of filaments. C—Cell where the transformation of the neurofibrils into filaments commences. a—Axone. b—Perinuclear neurofibrils.

A marked change is noted in the relations and conditions of the neurofibrils. Individually they seem to become hypertrophied and thickened. The rich neurofibrillar net disappears. The fibrils pass through the cells as conspicuous strands. Ultimately they break up into fragments and disappear.

When the neurone reaches this stage of degeneration, there occurs a marked reaction in the neuroglial cells, particularly those of the pericellular type. These cells undergo rapid proliferation and almost completely surround the diseased neurocyte.

If the affected nerve cell does not ultimately succumb, its constituents begin to reestablish themselves in the reverse order of the primary involvement. Nissl's bodies begin to reappear, the nucleus resumes its central posi-

tion, the neurofibrillar network makes its appearance and the increase of neuroglial cells no longer exists. When this is the case, a process of regeneration is accomplished, the neurofibrils, in consequence of their reappearance in the cell body, soon begin to grow out into the axone and the nerve cell finally reestablishes its connections.

2. The Syndrome of Secondary or Wallerian Degeneration. This syndrome is the result of injury or disease, not of the cell directly but of its chief process, the axone. The lesion may be at some distance from the cell body or relatively near to it. In this latter event, marked changes occur in the cell secondary to the axonal disturbance. These alterations are in many ways similar to those already described in primary degeneration. There is, however, a conspicuous difference in the reactions within the cell body. Nissl's bodies disappear by a process of chromatolysis, although in this case the solution begins in those bodies immediately about the nucleus and extends peripherally toward the essential membrane of the cell. The cytoplasm, the nucleus, and the neurofibrils react in a manner similar to that already described in primary degeneration, while the axone, peripheral to the lesion, undergoes a series of changes which will be discussed in detail in considering the nerve fibers.



FIG. 71.—Two spinal ganglion cells of an old man. Osmic acid coloration. (Cajal.)

a—Large pigment granules. b—Smaller granules. c—Satellite cell. d—Site of origin of the axis cylinder.

GENERAL SUMMARY OF THE NEURONE

A review of the general features of the neurone indicates that it has many elements in common with the somatic cell.

1. It possesses an *essential limiting membrane*, *cytoplasm*, a *nucleus with chromatin bodies* and several *nucleoli*, but it is entirely devoid of a *centrosome*. This latter fact deprives it of the possibilities of reproduction.

2. The organs constituting its cytoplasm are designed for two distinct purposes. First, *cellular metabolism*, and second, the *conduction of nerve impulses*.

3. The cellular organs pertaining to metabolism are: the *cytoplasmic framework*, the *cytoplasmic fluid*, the *tubular apparatus of Holmgren-Golgi*, the *chromophilic substance* or *Nissl's bodies*, the *pigmentary concretions* and the *fuchsinophile granulations*.

4. The organs which provide for the conduction of nerve impulses are the *neurofibrillar network* and the *perifibrillar substance*.

5. The neurone, like other cells of the body, possesses a soma or body, but unlike most other cells, it is equipped with certain processes which are of two varieties, the *dendrites* or *protoplasmic processes* and the *axone* or *neurofibrillar process*.

6. The neurone is possessed of a *dynamic polarization*, that is to say, the impulses which come to it make their entrance into the soma by way of the dendrites and leave the cell by way of the axone.

7. The dendrites or protoplasmic processes of the neurone are confined to the gray matter of the central nervous system or else to the gray matter forming ganglia. The axones may confine themselves entirely to the gray matter but a vast number of them pass beyond this limit and, becoming collected in a dense fascicular mass, constitute the medullary or white substance of the central nervous system and the peripheral nerves.

8. Nerve cells which send their axones into the white matter of the central nervous system or into the peripheral nerves are known as *Golgi type I*. The neurones whose axones never leave the gray matter are known as *Golgi type II*.

9. Each nerve cell, comprised of its three major parts, the soma, the dendrites and the axone, constitutes a morphologically and physiologically independent unit, the *neurone*.

CHAPTER V

THE INTEGRATION OF THE NEURONES TO FORM THE NERVOUS SYSTEM

THE NEURONE THEORY

The Manner in which Nerve Cells Establish Intercommunications. For the purpose of generating nerve impulses and conducting them through the nervous system, it is essential that myriads of nerve cells be brought into relation with one another. The means by which neurones are connected and the manner in which a number of such cells, although widely separated, may be mutually engaged in the performance of a common function, is the fundamental problem concerning the organization of the nervous system. Before it is possible to consider the means of intercellular communication or what may more properly be termed *neurone integration*, it will be necessary to have a clear idea of the various types of cells whose differences in form impose upon them differences in the means of communication. In general, intercellular communication is accomplished by cell processes, that is, by the dendrites and the axones. Nerve cells show such variations in this regard that the following groups may be distinguished:

Cells Encountered in the Nervous System, Classified with Reference to their Means of Intercellular Communication.

- I. Cells having a somatofugal process only.
 1. Cells with relatively short prolongations and without myelin sheaths; (cells of the retina and of the olfactory bulb).
 2. Cells with long prolongations (interstitial gland cells, intestinal sympathetic cells).
 3. Cells with long prolongations and with myelin sheaths (unipolar cells of the mesencephalic nucleus of the fifth nerve).
- II. Cells with processes for receiving and dispatching nerve impulses (somatopetal and somatofugal).
 1. Sensory cells provided with one receiving process and one axone (unipolar olfactory cells, cells of the retina, ganglion spirale (cochlear), ganglion of Scarpa (vestibular), dorsal root ganglionic cells connected with the spinal cord and the cranial nerves).
 2. Cells provided with several receiving processes and one long axone (motor cells of the cord and brain stem, most of the cells of the cerebral cortex, sympathetic cells, association and projection system cells of the central nervous system).
 3. Cells provided with several receiving processes, and a short axone (cells of Golgi type II, cells of the cerebellum, and many cells in the cerebral hemisphere).

4. Cells provided with several dendrites and one long axone which divides to continue as several branches in the white matter of the central nervous system (tautomerism and heteromerism intersegmental and intrasegmental cells having a T-shaped axone found in the cerebellum, in the spinal cord and in the brain).

Dynamic Polarization. The dendrite conveys the nerve impulse toward the cell body, while the axone serves to carry it away from the cell body to some destination more or less distant. Thus, two nerve cells might serve the purpose of conducting a nerve impulse in such a way as to permit passage from the first cell by its axone to the dendrites of the second cell. This simple mode of conduction from cell to cell does not hold good in all cases, since there are many cells which possess no somatipetal dendrites.

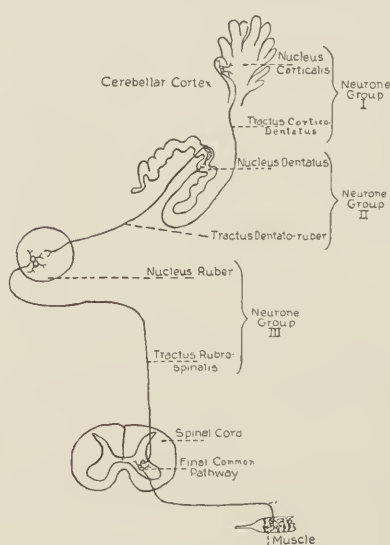


FIG. 72.—Cerebello-rubro-spino-effector pathway.

Some other means of establishing communication between such cells must be employed. In still other instances nerve cells are provided with bifurcated axones and a specialized type of intercellular communication is necessary for them. Deferring until later the consideration of these exceptions, the details of the intercellular communication which is most common in the central nervous system may be considered. This depends upon the somatipetal conduction of impulses by way of the dendrites and the somatofugal conduction by way of the axone, a mode of transmission which constitutes the basis for the law of *dynamic polarization* in the neurone. The nerve impulse leaving a multipolar cell passes by way of the axone to the dendritic end-brush or soma of the next cell that it is designed to influence. On

approaching this brush, the axone breaks up into interlacing terminal arborizations. How conduction is established at this critical point of junction has been a matter of debate for a long period.

The Neurone Theory. In view of the embryological investigations of His, and the histological studies of Cajal, Waldeyer in 1891 formulated the theory of intercellular communication which to-day is generally accepted. According to this interpretation, each neurone is an independent unit. It establishes connection with another neurone not by continuity but by contiguity of its neurofibrils. This conception of the unity of neurones and their communication by means of the contact of their processes is known as the *neurone theory*. In this manner nerve cells may be arranged in chains and groups of correlated chains, thus constructing special systems for the performance of definite functions.

The neurone theory has not, however, gone unassailed. Held in 1897

contended that there is a direct protoplasmic continuity from one nerve cell to the next by means of pericellular nets about the neurone and its dendrites. Apathy in 1897 also gave assent to the idea of cellular continuity on the grounds of his investigations upon invertebrates. It is his conception that there are two types of structures in the nervous system, *i.e.*, those which produce conduction, the neurofibrils, and those which produce nerve impulses. Bethe in 1897, although he could not agree with Apathy as to these two types of structures, expressed the belief that the nervous system, by reason of an anastomotic network, maintains a complete continuance through its neurofibrils.

Yet in spite of these objections, the neurone theory is still held by the consensus of opinion. It is particularly supported by the fact that the degenerative changes in the nervous system, due to any cause whatsoever, are usually limited to the neurone system immediately affected and do not spread to adjacent systems of neurones.

Contact Continuity—Synapsis. The critical point of contact by means of which nerve impulses are propagated from one neurone to the next is called the *synapse* or *synapsis*. Dependent upon the form and type of the cells, several varieties of synapsis may be observed:

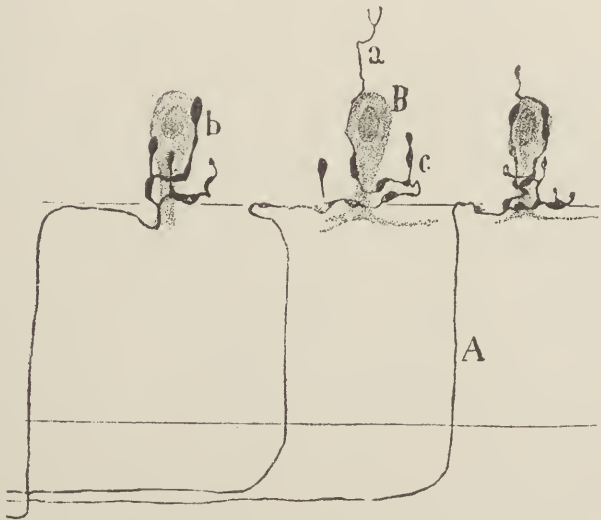


FIG. 73.—Centrifugal fibers in the retina of birds.
Method of Ehrlich-Bethe. (Cajal.)

A—Nerve fiber. B—Cell surrounded by arborization. a, b, c—Varicose end fibrils.

1. *The Axosomatic Synapse.*

In this type the end-brush of the axone terminates about the cell body. This type of synapse occurs in the Purkinje cells of the cerebellum, in the ganglion habenulæ, in the olfactory bulb, in the intestinal sympathetic cells and in many other cells of the central nervous system.

2. *The Axodendritic Synapse.* There are several forms of this type of intercellular communication: (a.) *Primary axodendritic synapse*, in which the articulation between one cell and the next is accomplished by the axone brush entwining itself about the protoplasmic trunks of the dendrite. These are known as *climbing fibers*. They occur in the Purkinje cells of the cerebellum, in Deiters' nucleus and in the protoplasmic processes of the red nucleus in the midbrain. (b.) *Terminal axodendritic synapse*, in which the end-brushes of the axone come in contact with the fine protoplasmic processes of the dendrite, as for example, in the cruciform contact found in the

motor cortex, in the cells of Purkinje and in the motor cells. A third variety of terminal axodendritic synapse is described in which there is a parallel arrangement of the contact processes. The contact connections of this variety are to be found in the glomeruli of the olfactory bulb, in the synapsis of the rod cells and the external nuclear layer of the retina.

Interpretation of the Centralization of the Nervous System. The neurone theory offers a satisfactory explanation of the mode of integration in the different parts of the nervous system. It does little, however, to make



FIG. 74.—Ascending end arborization, human cerebellum. Method of Cox. (*Cajal*.)

a—Ascending fiber. *b*—Purkinje cell.

clear the process which led to such a complex organization so placed as to become the central controlling organ of the body.

The necessity for this centralization of the nervous system is unquestionably to be found in the evolution of animal motion, by means of which the living animal makes its adaptation to the environment. If the environment is simple, little adaptation is needed and motion is correspondingly simple. Where the adaptation is of this kind, the motion may involve a single limited part of the body. The entire reaction, beginning with the receipt of the stimulus which is to elicit the motor response and ending with the transformation of the stimulus into contractile activity, may be carried on by a

mechanism intrinsic in a single part. When the environment is more complex or the animal is able to deal with a simple environment in a more varied manner, much greater requirements are made upon it in the way of adaptation, and the combinations of motions become more complicated. Such would be the case in an animal whose adaptive reactions require the cooperation of several allied parts of the body. The interaction of these parts would be dependent upon a coordinated controlling mechanism, since such regulation of motion could not be left to a diffuse and scattered set of organs. During



FIG. 75.—Basket cell of the cerebellum of a white mouse. (Cajal.)

A—Purkinje cell shaded with osmic acid. B—Basket cell. a, b—Pericellular nerve ramifications forming baskets. c—Axis cylinder.

the process of the evolution of motion, Cajal recognizes five epochs through which centralized control has passed.

1. THE EPOCH OF IRRITABILITY. During this period, a stimulus received by the surface of the animal is transmitted to a part closely adjacent to that in which it arose, and so affects certain contractile structures as to produce a limited, immediate movement. No intermediate tissue is needed for this conduction, because the transmission of the stimulus is made direct from the area receiving it to the contractile elements of that same area. It may even be that there is no intermediate step in the transmission of the impulse, but that it falls at once upon the tissue which is to respond by contraction. This kind of motor adaptation will, of course, be expected of very lowly animals whose necessities in adaptation are slight. It is the kind of reaction which is witnessed in the motor functions of the *Porifera* or sponges, for here the reaction to an afferent impulse is confined to a very limited portion of the cellular organism. It would be impossible for such an animal to carry on extensive coordinated actions or be capable of performances which serve the purposes of complex ends. It is sufficient that the motor response should be limited, for in a general way the animal is composed of more

or less independent unit-structures each one of which can carry on its own existence. In any event, no great amount of coordinated action is required, and its method of response is, therefore, relatively simple.

2. THE EPOCH OF THE REFLEX ARC. A significant step forward is taken when the stage is reached in which several parts of the body may be made to participate in response to a single stimulus. Such is the case when a stimulus is received by the receptor *A* and at once transmitted to the more or less independent effectors *B*, *C* and *D*, which at once go into action as a result of the impulse transmitted to them from the receptor *A*. This reaction requires the introduction of an intermediate element, for the reason that too many obstacles would stand in the way and too great a dispersion of energy

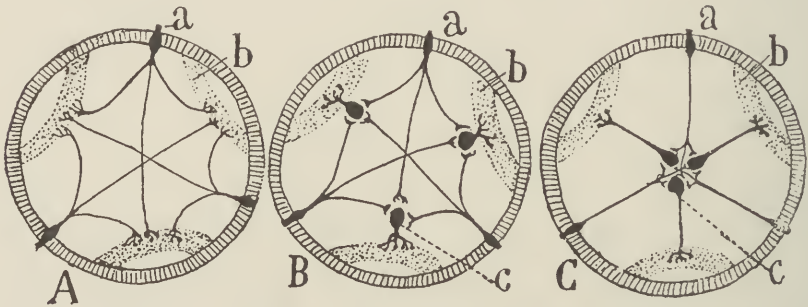


FIG. 76.—Diagrams showing the advantage of the multiplication of the neurones and of their grouping in central ganglia. (Cajal.)

A—Imaginary invertebrate in which it is supposed only cutaneous or sensory neurones exist (*a*). *B*—Invertebrate, possibly a sea-anemone, in which the two kinds of neurones already exist, motor (*c*) and sensory (*a*), but are not yet centralized in ganglia. *C*—Invertebrate, of the worm species, in which motor neurones (*c*) are concentrated in ganglia. *a*—Sensory or cutaneous neurone. *b*—Muscle. *c*—Motor neurone.

would result were the impulse to be transmitted directly from one cell to another until all of the parts designed to participate in the reaction had been properly stimulated. The evolution of this intermediary element resulted in the appearance of the *fundaments* of the nervous system. It was effected by the specialization of cells so differentiated that they were capable not only of receiving impulses but of transmitting them as well. The cells specialized to receive the impulses became the *receptor system*. The cells differentiated to transmit the impulses received and produce a motor response constitute the *effector system*, while the conjunction between these two systems establishes the *reflex arc*. With the development of this reflex arc to operate in the control of motion, the connection by means of synapsis between the receptor and effector cells affords the simplest illustration of the *neurone theory*. Certain of the invertebrates furnish examples of the epoch of the reflex arc, such as the Celenterates (the sea anemone and corals). In these animals, the afferent stimulus is diffusely retroflexive by a spread of the impulse from a limited area of reception to an extensive area of reaction through a reflex arc. In contrast to these forms, the sponges typify a discretely reflex action of the afferent stimuli, which are received from a relatively small region and determine a response in a correspondingly small area of action.

3. THE EPOCH OF THE INTERSEGMENTAL REFLEX NEURONE. Animal motion could not increase in its complexity and multiply the ability with which it was able to deal with the increasing variety in the environment, unless the many parts which were to participate in the motor reactions became more specifically adapted. There are reasons to believe that the segmented type of body structure lends itself more readily to greater complexity of animal motion than body structure of other types. When the body became segmented, therefore, the nervous system reflected this segmental character in segments of its own. Each segment controlled a definite territory which it brought into cooperative activity with other territories and parts. This result was accomplished by the development of neurones which con-

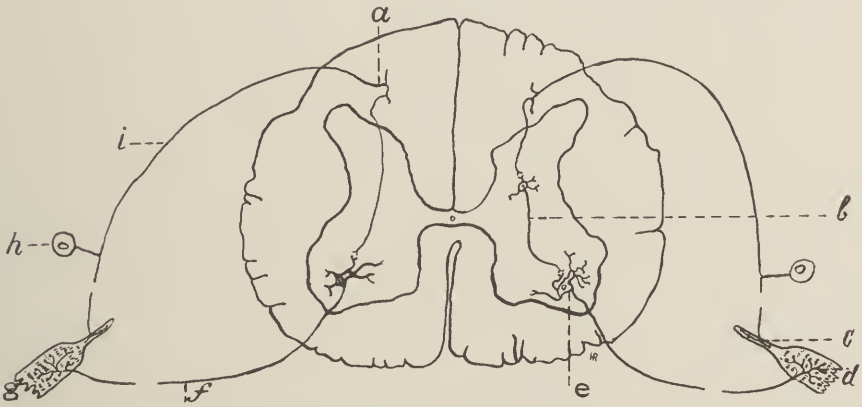


FIG. 77.—Diagram representing the two theories of the single reflex arc. On the left, the reflex is indicated as a two-neurone mechanism, on the right as a three-neurone apparatus. The entering dorsal root fiber is indicated as dividing into a long ascending and a short descending branch, either one of which may give origin to the collateral which affords connection either directly or indirectly with the ventral horn cell.

a—Entering fiber. b—Intercalated neuron. c—Musculo-tendinous organ of Golgi. d—Motor end organ in muscle. e—Ventral horn cell. f—Motor fiber. g—Muscle. h—Dorsal root ganglion cell. i—Sensory fiber.

nected one segment of the nervous system with several others, the *intersegmental reflex neurones*.

4. THE EPOCH OF THE SUPRASEGMENTAL REFLEX NEURONE. The next advance was marked by the addition of another order of neurones which were not strictly confined to the segmented portion of the nervous system. They constituted a structure which made its appearance in response to new demands for more extensive neural control and more complex combinations of motion. Prior to this epoch, the reflex arc and the intersegmental reflex neurone sufficed to regulate the motor reactions in the behavior of the animal. In the first place, all of the motions during this period were immediate responses, that is to say, reflex actions in the strict sense which were represented by the translation of sensory stimuli into motor impulses without appreciable delay. This fact in itself serves to explain the character of the resultant behavior whose limited scope and stereotyped form imparted

to all of its reactions a pronounced inflexibility. Under given circumstances one set of reactions, and one set only, could be expected as the result of given stimuli. Furthermore, the combinations of these stereotyped performances are themselves limited in their scope and rigid in their form. Since these reactions are dependent upon the coordination of several segments of the body, economy of space and material would require that their controlling elements should not be separated by great distances from each other, but should be brought together in some centralized position, such as that occupied by the nervous system. These influences have played an

important rôle in the process of centralization.

When, however, it became necessary to extend the scope and form of behavior by increasing the motor performances which entered into it, another element was requisite for controlling organs of the body. The need was not so much for a complication in the combination of possible motions, as it was for the specific adaptation of motions to more complex purposes. The essential element in this adaptation was the factor of time. Heretofore there was no appreciable interval between the receipt of a stimulus and the dispatching of the motor impulse, so that the reflex act was an immediate

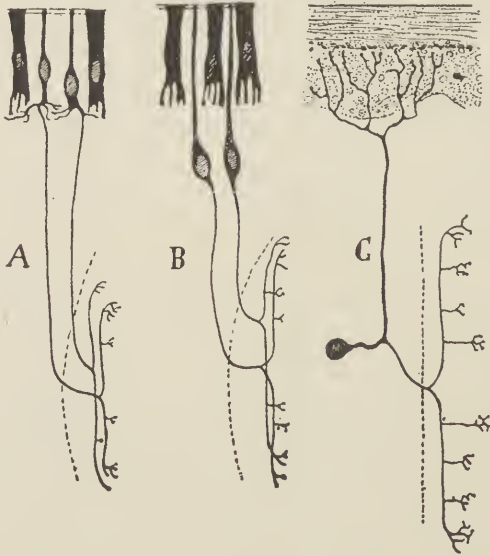


FIG. 78.—Scheme of the progressive centralization of the sensory cells in an animal series. (Cajal.)

A—Sensory neurones of the earth-worm. B—Sensory cells of a mollusk. C—Sensory cell of a vertebrate.

consummation in motion. Oftentimes this very rapidity of discharge would defeat the accomplishment of some higher purpose, for a delay of even a fraction of a second might eventuate in determining circumstances more advantageous to the animal's activities. This pause in the reflex reaction time, this period of latency, furnished an interval for reflection, as it were, in which a selection between alternatives might be made and the one, proven by experience to be the most advantageous, might be chosen to guide the resulting acts. This would be the first step in introducing a more plastic type of behavioral reaction. The new element which produced the period of latency by holding in check the response until the most favorable moment had arrived would, in its essential nature, provide the important factor of *inhibition*. The nervous system, when this epoch was reached, had come under the guidance of a new influence and acquired the far-reaching quality

by which it is able to withhold action until it is most opportune and profitable. In this sense, behavior is no longer a matter of instantaneous impulse, but is made subject to a certain simple degree of supervisory review, guided by a primitive form of judgment which may be taken to mark the beginning of the psychic life. If centralization became necessary in the epoch of the intersegmental reflex neurone, it was now even more essential, for reasons both of economy in space and of time in conduction, that the controlling organs should occupy a central position. Thus from the earliest epoch there have been urgent reasons for the concentration of neural control in a central system.

5. THE EPOCH OF THE PSYCHO-ASSOCIATIONAL NEURONE. The final step in the centralization of the nervous mechanism, enabling it to attain the consummation of its functional capability, arrived with the addition of the psycho-associational neurone. By this means numerous associations are made possible between the various types of sensibility, including somesthetic sense, vision, hearing, taste and smell, out of which the experience of the individual is constructed and upon which the foundations of the higher faculties rest.

The Essential Relation of the Receptors to the Effectors. The underlying, universal principle throughout this entire process of evolution has been the maintenance of an adequate relation between the receptors and effectors of the body, together with the constant expansion of the functional potentialities of this relation. In other words, the more broadly and deeply an animal senses its environment by means of its afferent sensory mechanism, the more extensively and satisfactorily it reacts by means of its effector mechanism. The animal recognizes the labile character of its environment through its receptors and is able to make its accommodation to ever-changing conditions by its effectors.

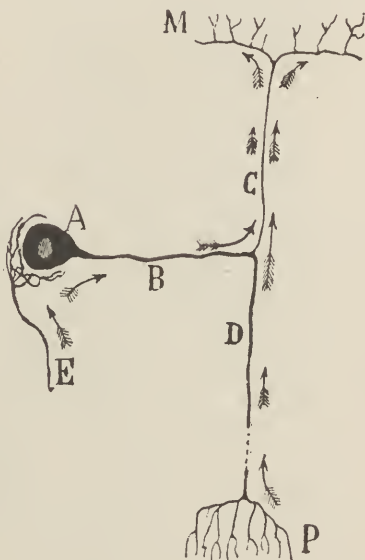


FIG. 79.—Diagram of the course of an impulse in a sensory cell of the mammalian spinal ganglion. (Cajal.)

A—Body. B—Trunk. C—Central branch, thin, acting as axis cylinder and coursing toward the cord. D—Peripheral branch, thick, performing the function of prolonging the protoplasm and bringing the current from the periphery. E—Fiber furnishing the pericellular arborization to the body of the ganglion cell. M—Spinal cord. P—Skin. The course is indicated by the direction of the arrows.

THE RECEPTORS

The fundamental condition observed in the epoch of surface irritability, in which the receptors and effectors are practically in one and the same tissue, has been retained during the process of evolution. Although there has come about a great separation in space between the receptors and the

effectors, and an intermediary agent—the nervous system—has developed between them, it is still the essential relation between the structures which receive the impulses and those which translate them into motions that characterizes the nature of the nervous mechanism through all of the epochs which have been described.

The classification of the receptors is as follows: (1) *Exteroceptors*, those receiving organs which have developed in the ectodermal covering of the



FIG. 80.—Plexus in the cornea of a rabbit. Ehrlich's method. (Cajal.)

A—Framework of fundamental plexus. B—Sub-basal plexus. C—Interepithelial end branches. D—Subepithelial end branches.

body. (2) *Proprioceptors*, those receiving organs which have developed particularly in the mesoderm and more especially in relation to the muscles, joints and bones. (3) *Interoceptors*, those receiving organs which have developed in the entoderm, especially in connection with the viscera.

Exteroceptors. A great variety of exteroceptors have been identified in the ectodermal covering of the body. These fall into two large groups, (1) the *contact receptors*, and (2) the *distance receptors*.

CONTACT RECEPTORS. Two varieties of contact receptors are distinguished, namely, those situated in the epidermis, the *epidermal* or *intra-epidermal receptors*, and those situated in the dermis, the *dermal receptors*.

Epidermal Receptors. There are several types of these epidermal receptors:

1. *Receptors in the Cornea.* The arrangement of the end-organ in this structure is that of a series of plexus, consisting of a deep fundamental plexus of coarse fibers, situated beneath the epithelial structures, and a fine subbasal plexus. From this layer is derived a still finer subepithelial plexus which gives rise to the intra-epidermal terminations of free fibers between the cells of the cornea, or fibrils with varicosities upon them.



FIG. 81.—Terminations of nerves in the anterior epithelium of the cornea in an adult rabbit. Gold chloride method. The minutest nerve fibers are seen coursing between the epithelial cells and ending in varicosities on the corneal surface. (Cajal.)



FIG. 82.—Ivy-like (hederaceous) terminations in the interpapillary prolongations of the skin on the finger of a several days' old infant. By reduced silver nitrate method. (Cajal.) (See also Fig. 93.)

A.—Afferent fiber. a—Reticular end dilatations situated beneath the epithelial cells.

2. *Receptors in the Epithelial Portion of the Skin.* The sensory apparatus here consists of a dense subepithelial plexus from which arise numerous branching neurofibrils to form a rich arborization occupying an intra-epithelial position. These end-fibrils either terminate freely among the epithelial cells of the skin or become specialized to form the *tactile meniscus* or disc of Merkel. These discs are disseminated, ovoid corpuscles, consisting of epithelial cells which stain more deeply than the adjacent elements. Beneath these cells are concavo-convex discs of neurofibrils devoid of myelin sheaths.

3. *Receptors in the Ectodermal Mucous Membrane.* The sensory apparatus of the mucosa in regions where the cellular arrangement is cylindrical or columnar, is furnished by varicose neurofibrils and terminal buttons, while in stratified and pavement epithelia, the fibrils form nets with free branching, intra-epithelial, varicose terminations.

4. *Receptors about the Hairs.* The sensory end-organs with which hairs

are equipped are of two classes. The ordinary non-cavernous hair is innervated by two independent sets of nerve fibrils. One of these consists of circular fibrils which terminate in buttons or reticular nets. The other is a set of ascending fibrils which terminate about the vitreous tunic. The cavernous hairs, such as the vibrissæ, are innervated by a series of circular neurofibrils about the cavernous sheath and also by ascending fibrils in and about this

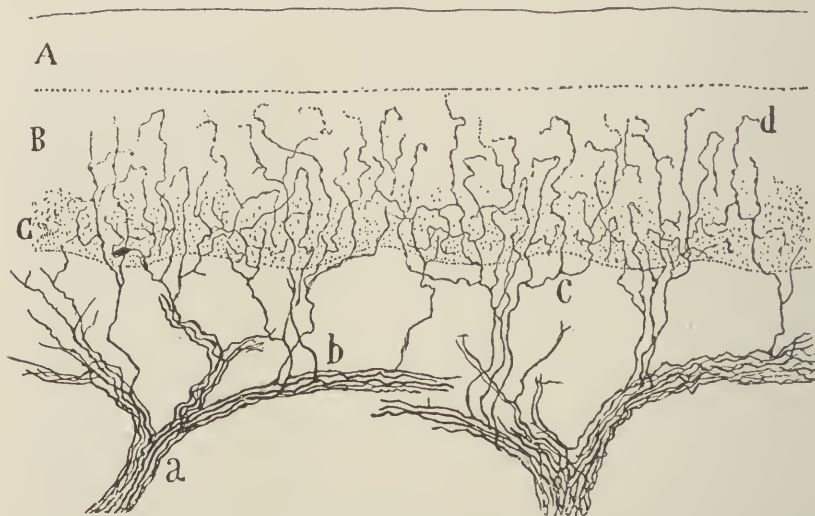


FIG. 83.—Terminations of nerves in the skin of the paw of a cat four days old. Golgi's method. (Cajal.)

A—Horny epidermis. B—Malphigian layer. C—Deep part of Malphigian layer sprinkled with grains of pigment. a—Large nerve trunks. b—Collateral fibers. c—End arborization. d—Terminal ends situated between the epithelial cells.

sheath. All of these fibers lose their myelin coverings before they terminate and then end either as a tactile meniscus about the vitreous tunic or as free varicose endings in the same position.

Dermal Receptors. The second large group of contact receptors is situated in the dermis. These are the dermal receptors. They present themselves as a variety of end-organs having highly specialized forms. They are less diffuse than the epidermal receptors, and are for the most part encapsulated. Physiologically, they depend for their reaction upon some degree of pressure upon the epidermal surface.

1. *The Corpuscles of Grandry-Merkel.* These end-organs are found in the submucosa of the tongue and mouth. Each corpuscle consists of an outer conjunctivo-endothelial sheath which is continuous with the sheath of Henle of the nerve. Enclosed within this sheath are two voluminous epithelial cells more or less hemispherical in shape and opposed to each other by a flat or concave surface. Between these opposed surfaces is a biconvex disc containing the ends of the neurofibrils. The corpuscles of Grandry-Merkel may be simple or compound. When simple they are made up of a single neurofibril ending between the two epithelial cells.

When compound, several neurofibrillar endings may be invested by epithelial cells and included in a single conjunctivo-endothelial sheath.

2. *Tactile Corpuscles of Meissner*. These end-organs are found in the tips of the fingers and toes, in the skin over the lips, in the mammæ and the external genitalia. They occupy the summit of the dermal papillæ which, for this reason, are known as the *neural papillæ* of the skin. They are so placed that their long axis is perpendicular to the skin surface. They are ovoid in form, but may be tuberous or lobulated. Their size varies from 30 to 50 micra in length and 20 to 30 micra in thickness. These corpuscles usually alternate in the skin with the *vascular papillæ*. The corpuscle of Meissner consists of a thick, fibrous capsule, a granular central substance and a terminal arborization of nerve fibers, constituting a rich spiral reticulum which tends to taper as it approaches the summit of the end-organ. The capsule of the corpuscle of Meissner is rich in cells, although it is relatively thin.

3. *Corpuscles of Krause*. These end-organs present a simple and a complex type. The *simple form of the corpuscle of Krause*, the *end-bulb*, has been considered by authorities as a corpuscle of Pacini in its most reduced and simplest form. It consists of a fibrous structure resembling the corpuscle of Meissner and also contains a portion

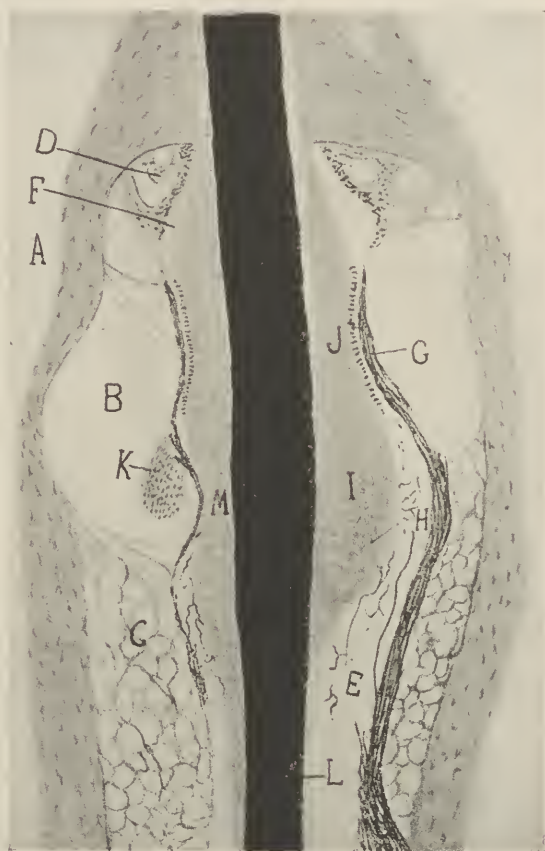


FIG. 84.—Longitudinal section of a tactile hair of a rat. (*Tello*.)

A—External conjunctival sheath. B—Annular sinus. C—Cavernous portion of the vascular sheath. D—Region of the nerve rings. E—Internal conjunctival sheath. F—Superior dilatation. G—Afferent nerve fibers. H—Free arborizations. I—Epithelial envelope. J—Superior constriction with the series of the cut tactile meniscuses. K—Annular protuberance. L—The hair. M—Inferior constriction.

of the sheath of Henle which extends from the nerve fiber. In addition, there is a central granular mass which is cylindrical in form and has a rounded extremity. In the midst of this granular mass is a neurofibril of the nerve termination. The *complex type of Krause's corpuscle* resembles in many ways the corpuscle of Meissner except that it is enclosed in a much thicker sheath, is more spherical in form and contains a richer plexiform arrange-

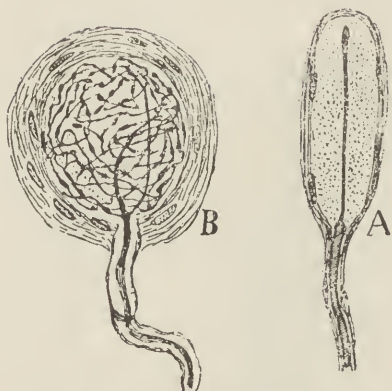


FIG. 85.—Two corpuscles of Krause in the conjunctiva. Ehrlich's method. (Cajal.)

A—Simple type in conjunctiva of an ox.
B—Complex type in conjunctiva of man.

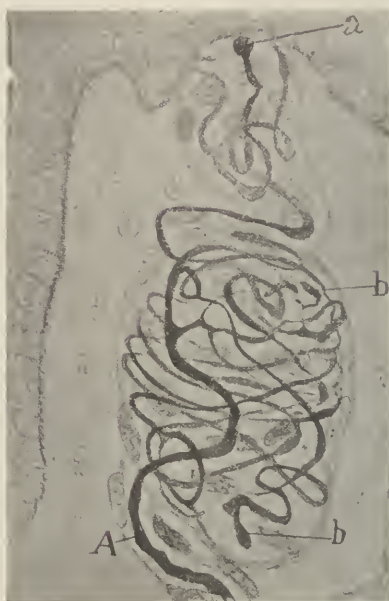


FIG. 86.—Corpuscle of Meissner in the human skin. (Cajal.)

A—Afferent sensory fiber. a—End button situated under the epidermis. b—Termination of the branches of nerve fibers.

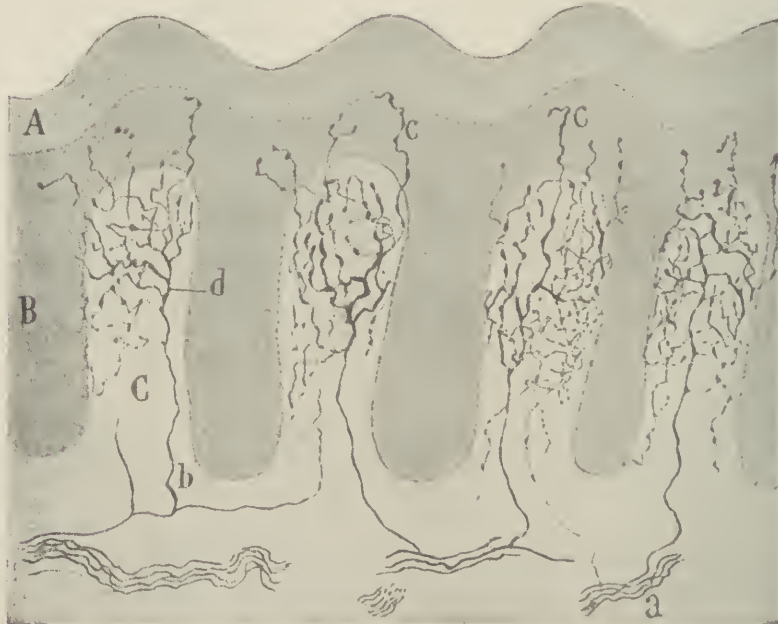


FIG. 87.—Nerve terminations in the anterior portion of a cat's tongue. Ehrlich's method. (Cajal.)

A—Horny epithelium. B—Malpighian layer. a—Subepithelial nerve fasciculus. b—Branch on the way to a lingual papilla. c—Intra-epidermal fibrils. d—Lingual papilla.



FIG. 88.—Genital corpuscle in the human glans penis. Method of Ehrlich. (Cajal.)

a—Nerve fibers. b—Capsule. c—End arborization.

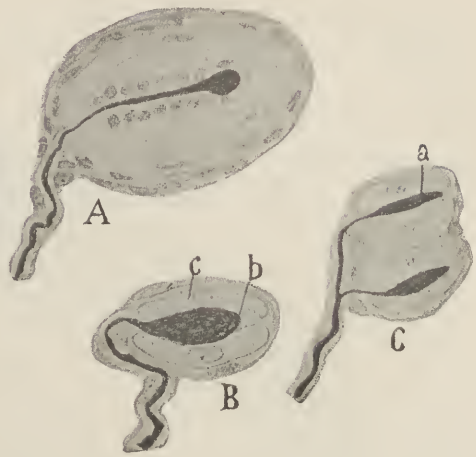


FIG. 89.—Nerve terminations in the border of a duck's tongue. Silver nitrate reduction. (Cajal.)

A—Corpuscles of Herbst. B—Simple corpuscle of Merkel. C—Another corpuscle of Merkel supplied with two terminal discs. a, b—Bulbous termination of nerve fiber. c—Epithelial cell.

ment of neurofibrils within the central granular mass. Both forms of the corpuscles of Krause are found in the conjunctiva and in the skin of the external genitalia. A highly complex form of Krause's corpuscle identified in the mucous membrane of the external genitalia is described as the *genital corpuscle of Dogiel*.

4. *Corpuscles of Pacini*. These end-organs are the largest of those encountered in connection with the skin. They are ovoid in form, vary from 1 to 2 millimeters in length and are scattered throughout the subcutaneous tissues. In the pulp of the fingers they are encountered in greatest number. They are also found upon the course of nerves, in ligaments, in interosseous membranes, in the perimysium and endomysium of muscles, in the mesentery and mesocolon. They are composed of a granular central bulb made up of a series of concentric capsules. These capsules consist of connective tissue laminae separated from one another by lymphatic spaces and containing many endothelial cells. In the

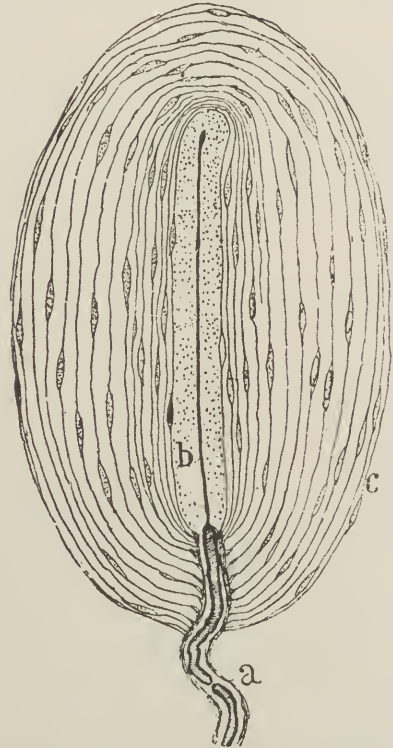


FIG. 90.—Corpuscle of Pacini in the human skin. Gold chloride method. (Cajal.)

a—Sheath of Henle of the afferent fiber. b—Central granular substance. c—Capsules.

center of this bulb-like structure is a single terminal nerve fiber surrounded by granular substance. This laminated bulbous organ is the most common



FIG. 91.—Corpuscles of Timofceew, prostatic capsule of a dog. Ehrlich's method. (Cajal.)

A—Large fiber in continuation with the axial trunk of the corpuscle. B—Minute fiber, ramifying around the granular substance (after Timofceew).

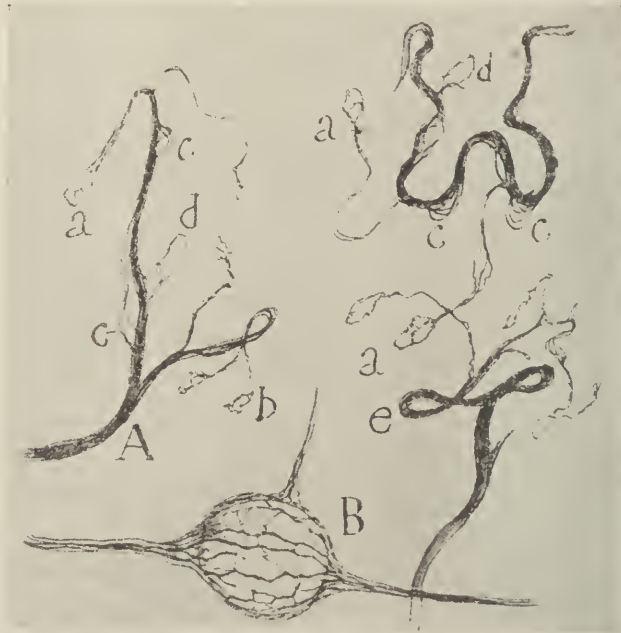


FIG. 92.—Details of the neurofibrillary framework in the granule cells and arborizations of the mossy fibers in the cerebellum of an adult cat. Silver nitrate reduction. (Cajal.)

a—Principal trunk of the mossy fiber. b—Loops and terminal plexuses. c, d—Complex loops. e—Twinings in the form of a figure 8. A—Protoplasmic process. B—Body of the cell.

form of the corpuscle of Pacini. There are, however, several varieties of the Pacinian body, such as the *organs of Herbst*. These structures consist of a single central neurofibril surrounded by a large granular mass with a thin, conjunctivo-endothelial capsule. The *organs of Golgi-Mazzoni* are also

small Pacinian bodies found at the junction of tendons with their muscles. They are long, cylindrical structures enveloped in a well-defined capsule.

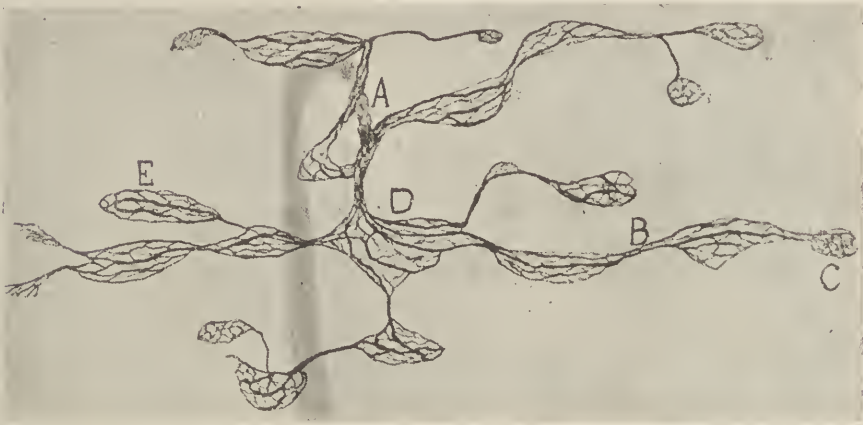


FIG. 93.—Tactile menisci produced by a solitary nerve fiber in a rat. (Cajal.)

A—Division of the fiber. B—Constriction of the branches. C, E—End enlargements showing the disposition of the neurofibrils. D—Enlargements at the points of division.

5. *The Corpuscles of Timofeew.* These end-organs are a specialized form of the Pacinian body. They are found in the submucosa of the membranous and prostatic portions of the urethra and in the prostatic capsule. The corpuscle is a long, ovoid body with a conjunctivo-endothelial capsule made up of concentric layers. It contains a large mass of central granular material and is penetrated by two nerve fibers, in which detail it differs from the corpuscles of Pacini.

Distance Receptors. This group of receptors is represented by a series of specialized end-organs which receive impressions borne to them through air or through water.

Distance Receptors for Smell. These end-organs are stimulated by aromatic and volatile substances which act upon the specialized olfactory mucous membrane of the nose. The peripheral organ of smell consists of an epithelium containing sensory cells which give rise to the fibers forming the olfactory nerve. These cells are bipolar. Their central processes enter into the formation of the *fila olfactoria*, while their peripheral processes are equipped, at their extremities, with a number of hair-like prolongations, the *olfactory hairs*.

Distance Receptors for Vision. The visual end-organ is in the retina. It is capable of response to stimuli of a series of vibrations ranging between 400,000,000 and 800,000,000 per second.

Distance Receptors for Hearing. The end-organ of hearing is responsive to air vibration whose frequency ranges from 30 to 30,000 per second. The actual receptor is the *spiral organ of Corti* situated in the cochlea of the internal ear.

Proprioceptors. The proprioceptors are usually classified in two groups, (1) the sensory end-organs in the muscles and tendons, and (2) the specialized end-organs of the vestibular portion of the internal ear.

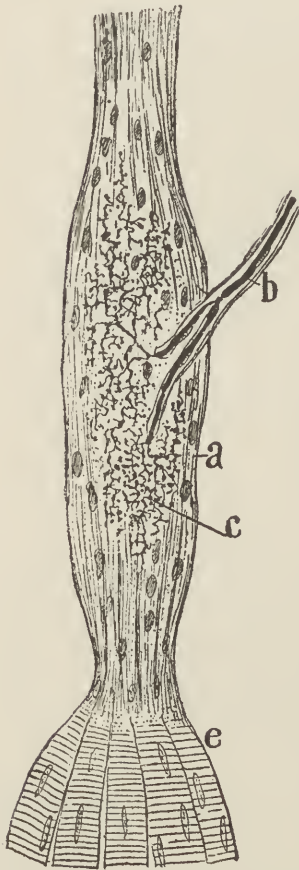


FIG. 94. — Musculo-tend, inous organ of Golgi-adult cat. Gold chloride method. (Cajal.)

a—End-arborization. b—Nerve fiber. c—Terminal branches of the end-arborization. e—Muscular fibers.

SENSORY END-ORGANS IN THE MUSCLES AND TENDONS. *The Muscle Spindles of Kühne.* These end-organs are found in striated muscles scattered among the muscular fibers. Each of these end-organs consists of a capsule containing a central gray substance, in the midst of which are the unmyelinated neurofibrils forming a rich terminal arborization.

The Musculo-Tendinous End-Organs. Four general varieties of such end-organs are recognized: (1) The *musculo-tendinous terminations*; these are known as the *musculo-tendinous end-organs of Golgi*. They are placed at the junction of a tendon with the muscular fibers and are found only in such muscles as have great importance or great strength, as for example the calf-muscles in man, and the muscles of the eye. They consist of a thin, conjunctivo-endothelial envelope, a considerable mass of central gray matter in which ramify the terminal branches of the neurofibrils. Functionally, they serve for the musculo-tendinous sense and are essential to the orientation and control of motor activities. (2) The *corpuscles of Golgi-Mazzoni* have already been described as a variety of the Pacinian bodies situated in the musculo-tendinous apparatus. (3) The *terminations of Sachs and Rollet* of reptiles and amphibia are considered rudimentary forms of the corpuscles of Golgi situated between the fasciculi of the tendons. (4) The *terminations of Ruffini* have a distinct resemblance to the musculo-tendinous corpuscles of Golgi. They are distinguished, however, by their

topography, for they do not appear in the tendons but in the subcutaneous tissue, in the aponeuroses and the intermuscular fascial planes.

END-ORGANS IN THE VESTIBULAR PORTION OF THE INTERNAL EAR. These end-organs consist of a highly specialized group of receptors connected with the semicircular canals, the utricle and saccule of the internal ear. Their special function is concerned in the maintenance of equilibrium. They receive impulses transmitted to them by the endolymph contained in the membranous semicircular canals, utricle and saccule.

Interoceptors. The interoceptors are the end-organs for visceral sensibility and are divisible into two groups: (1) *General visceral receptors*, which are but little specialized organs, innervated through the sympathetic

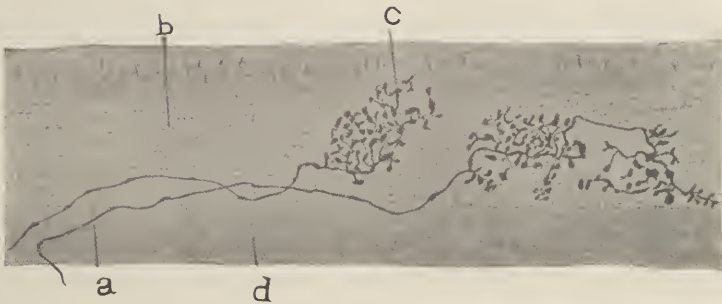


FIG. 95.—Sensory terminations in the adventitial arterial membrane of a cat. Ehrlich's method. (Cajal.)

a—Sensory neurone. b, d—Arterial wall. c—Terminal arborization.

system. (2) *Special visceral receptors*, which are provided with highly developed end-organs and are innervated directly from the brain and are not connected with the sympathetic system.

General Visceral End-Organs. Of the general visceral group of receptors not much is definitely known, although it is presumed that end-organs are provided for hunger, thirst, respiratory sensations and visceral pain. As a rule, the nerve endings of the general visceral receptors are either simple terminals in the visceral muscles or free arborizations in or beneath the mucous surfaces, without the development of special accessory cells to form differentiated end-organs.

Special Visceral End-Organs. End-organs for the sense of taste compose this group. They are excited by chemical stimulation and consist of taste-buds on the tongue and pharynx. These organs are responsive to sweet, sour, salty and bitter substances. The end-organ is a flask-like collection of specialized epithelial cells supporting the specific sensory ending. The taste-buds are usually situated on the tongue in certain papillæ which surround the end-organs. At the apex of the papilla is the taste pore through which the fluid reaches the sensory cells.

EFFECTORS

The effectors, by means of which nerve impulses are distributed to the muscles and glands, are of two varieties: (1) *somatic effectors*, and (2) *visceral effectors*.

The Somatic Effectors. These effectors consist of the motor end-organs and the striated skeletal muscles. These organs are made up of an end-plate which is a complex terminal arborization of the motor fiber, imbedded in an elevated, granular mass of cytoplasm and a collection of nuclei in the muscle fiber.

The Visceral Effectors. These effectors consist of the motor end-organs



FIG. 96.—Spindle of the pectoro-cutaneous muscle of a frog. In the inferior part, at *B*, is seen the ordinary motor termination; the superior part, on the contrary, shows the sensory termination. On account of the great distance separating these two terminations, a part of the striated muscular fiber has been left out. (*Cajal*.)

a—Sarcolemma. *b*—Afferent nerve fiber. *c*—Branch of *b*. *d*—Terminal varicose endings. *B*—Efferent or motor fiber.

and the involuntary muscles, which may be unstriated or striped, as in the case of the heart. They are branched, free terminals ending on the surface of the muscle fiber. In the case of the heart muscle, the nerve fibers usually have expanded tips. The end-organs of the glands are fine unmyelinated fibers derived from the sympathetic system. These envelop smaller glands and make their way through the larger ones.

FUNCTIONAL SIGNIFICANCE OF THE SOMATIC RECEPTORS

Simple Tactile Sensibility (Thigmesthesia). This type of sensibility is tactile sense in its simplest form. The receptors for it are situated either about the hairs or constitute the tactile discs of Merkel.

Critical Tactile Sensibility (Topesthesia). This type of sensibility is particularly characteristic of the hairless parts of the skin, the palms of the hands, the soles of the feet, and the lips, which are sensitized to a high degree of tactile discrimination, as indicated by their ability to localize areas in these parts and distinguish the distances between two points (Weber's compass test). The receptors for this type of sensibility are the corpuscles of Meissner and the corpuscles of Grandry-Merkel.

Pressure Sensibility of all Grades (Piezesthesia). The receptors for this type of sensibility are specialized end-organs having a wide distribution in the body, the corpuscles of Pacini and their modifications.

Muscle-Joint Sense (Myesthesia, Arthresthesia). The receptors for this type of sensibility are the muscle spindles of Kühne, the musculo-tendinous end-organs of Golgi, the corpuscles of Golgi-Mazzoni and the endings of Ruffini.

Pain Sensibility (Algesthesia). The receptors for this type of sensibility are probably the free endings which are either intra-epithelial, intramuscular or intrafascicular.

Temperature Sensibility (Thermesthesia). In this type of sensibility, two grades are rec-

ognized: the critical and the affective perception of heat and cold. The receptors of affective heat sensibility are in all probability the free intra-epithelial endings on the surface of the body, while critical heat sensibility, according to some authorities, is mediated through the corpuscles of Krause.

Equilibratory Sensibility. The receptors for this type of sensibility are the end-organs in the semicircular canals and the utricle and saccule.

The Special Senses of Smell, Sight and Hearing. These senses have their specialized receptors in the olfactory, visual and auditory organs.

PARTS WHICH AMPLIFY THE RELATIONS BETWEEN RECEPTORS AND EFFECTORS; THE MEDIATORS

The agent by which the receptors and effectors are maintained in their proper relation is the central nervous system. This relation is accomplished through neural connections which establish continuity in the flow of afferent impulses from the receptors and efferent impulses to the effectors. The cells in the nervous system which make this relation possible are the *mediators*. The connection may be simple, bringing but few cells into action, as in the *intra-segmental reflex*, or may require the cooperation of a large number of cells and several segments, as in the *intersegmental reflex*. For the most efficient action, the connection may demand the operation of the more complex portions of the brain and is then *suprasegmental*.

Nuclei, Tracts and Pathways. The association of the several parts of the central nervous system for the performance of the more complex *neural reactions* depends upon the functional combination of several superposed *neurone groups* to form a *pathway*. Each neurone group in the central axis consists of a collection of *tract cells* which constitutes a *nucleus* whose axones become collected to form a *tract*. Thus one important *cerebello-spinal pathway* is composed of three successive neurone groups brought into relation with each other by means of synapses and consisting of (1) the cortico-dentate group, (2) the dentato-rubral group, and (3) the rubro-spinal group.

In maintaining and providing the most efficient relations of the receptors to the effectors, these tracts and pathways form connections between the several parts of the central nervous system. As a result of these connections the receptors may produce an immediate response in the effectors called a *simple reflex action* or, by bringing the more highly developed parts of the brain into play, they may occasion an extensive correlation of nerve impulses which determines a complex, mediate response known as a *neural reaction*.

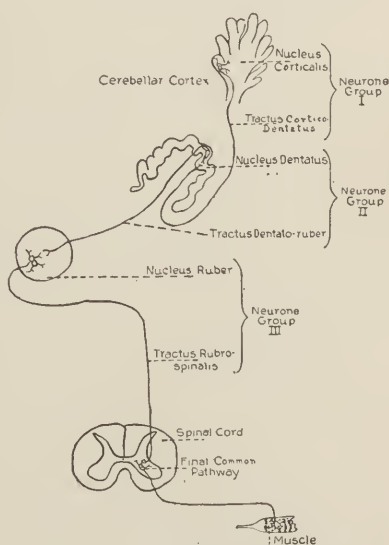


FIG. 97.—Cerebello-rubro-spino-effector pathway.

The parts of the nervous system which the tracts and pathways serve to integrate, in this manner and for these purposes are: (1) The spinal cord segments; (2) the medulla oblongata; (3) the pons and cerebellum; (4) the midbrain; (5) the interbrain, and (6) the cerebral hemispheres.

The spinal cord is also known as the *myelon*. The medulla oblongata, pons and cerebellum constitute the *rhombencephalon*, the midbrain is often referred to as the *isthmus encephali*. The interbrain and cerebral hemispheres comprise the *cerebrum*.

SPECIAL CLASSIFICATION OF THE RECEPTORS OF THE SKIN

According to Botezat the receptors of the skin may be classified as follows:

A. END-ORGANS OF THE EPIDERMIS

Simple Free Endings

(a) Specific Intra-epithelial Branching

1. Branching with end-knots
2. Thin branching with end-knots
3. Broad end-branches
4. Thick fibers with lateral nets (Tretjakoff)
5. Loose pericellular fiber nets
6. Simple indifferent branching

(b) Accessory Intra-epithelial Branching

Cellular Endings—Merkel's Corpuscles

B. END-ORGANS OF THE DERMIS

Simple Free Endings

(a) Fiber Nets (loops)

1. Papillary fiber nets and loops
2. Papillary fiber bundles (Ruffini)
3. Subepithelial fiber nets
4. Loose fiber nets

(b) Branches

1. End-branches on basal membrane
2. Simple widely branched end-trees
3. Complicated branched end-trees
4. End-branches in bone and cartilage

(c) Knots

1. Simple
2. Combined
3. Ruffini's Corpuscles
4. Genital Corpuscles

(d) Intercalary Corpuscles

1. Simple
2. Compound

Capsular Endings

(a) Krause's End-bulbs

1. Simple
2. Compound

- (b) Pacini's Corpuscles
 - 1. Simple
 - 2. Compound
- (c) Golgi-Mazzoni's Corpuscles
 - 1. Simple
 - 2. Compound
- (d) Capsular knots
 - 1. Simple
 - 2. With flat endings
 - 3. Genital corpuscles

Cellular Free Endings

- (a) Merkel's Corpuscles
 - 1. Simple
 - 2. Compound
 - 3. Grouped

Encapsulated Cellular Endings

- (a) Dogiel's Corpuscles
- (b) Meissner's Corpuscles
 - 1. Simple { Monolobar
Multilobar
 - 2. Modified { Simple
Combined

C. END-ORGANS IN THE HAIRY PART OF THE SKIN

Sparsely-Covered Skin

- Epidermis
 - 1. Simple
 - 2. Cellular (Merkel's Corpuscles)

Thickly-Covered Skin

- Epidermis
 - End-branching with end-knots.

CHAPTER VI

EXPOSURE AND INVESTIGATION OF THE SPINAL CORD *IN SITU*

Significance of Spinal Relations. The highest degree of integration in the nervous system is attained in the spinal cord and brain of man. Here the chief object of the integrative process is to assemble the nerve impulses flowing from the receptors in the most efficient combinations of nerve energy to influence the effectors of the body. Since the *myelon* or *spinal cord* is the more simple of the two major divisions of the central nervous system, it offers a convenient point of departure in the study of these central organs.

For the student of the nervous system, and especially for the surgeon, a complete exposure of the central nervous system is of value because it affords an accurate realization of the relations between the cord and its envelopes, membranous, fluid and bony. Also of importance to the diagnostician and operating surgeon are the relations between the levels of origin of the nerves in the cord and the points at which the nerves leave the vertebral canal to enter their peripheral course.

Incision Through Skin and Subcutaneous Tissues. *The preliminary incision* should be made through the skin and subcutaneous tissue from the *external occipital protuberance* to the *tip of the coccyx*.

A second incision curved in direction with its convexity upward should connect the tips of the two *mastoid processes*, its curve passing through the external occipital protuberance with the two lateral limbs of the incision corresponding to the superior curved line of the occipital bone.

Depth of Incision in the Several Regions. *In the cervical region* the incision should then be deepened through the *ligamentum nuchæ* down to the spines of the cervical vertebræ in order to separate the heavy masses of muscle on either side of the neck.

In the thoracic region, the muscle mass being so much thinner, the preliminary incision will be found to have passed down to the spines.

In the lumbar region, the incision has to be deepened, for in this as in the cervical region, there are thick layers of muscle overlying the vertebræ.

In the sacral region the vertebral column again closely approaches the surface, and the superficial incision will be found to be in contact with the underlying sacrum.

Separation of Muscle Masses. Beginning from below and passing cranially, the muscle mass should be separated from the spines and laminæ of the vertebræ by the use of a periosteal elevator. The muscle attachments should be scraped clean from the spines and laminæ in order to facilitate the opening of the vertebral canal.

Muscles and Fasciæ Exposed. Although the arrangement of the muscles in the thoracic and sacral regions is not regular enough to allow a separation into definite superficial and deep groups, nevertheless, in the cervical and lumbar regions, such a working differentiation can be made by means of the separation effected by more strongly developed fascial layers.

In the *cervical region* the deep fascia is attached to the *inferior curved lines of the occipital bone* and is carried down into the neck as a partition between groups of muscles which can be called superficial and deep.

In the *lumbar region* a similar layer may be made out stretching between the *ribs* above and the *crest of the ilium* below. This separates what may be called the axial from the paraxial muscles.

Arteries Encountered in the Exposure. In the *thoracic region* the arteries encountered are the small dorsal branches from the intercostal arteries which pass backward through the costo-transverse spaces together with the posterior primary branches of the spinal nerves which supply the muscles of the back. Anastomosis between these vessels in the muscle fascia layers may produce a vessel of small size situated on either side of the spinous processes and also along the line of the tips of the transverse processes.

A similar arrangement may be made out in the *lumbar region* where the branches come from the lumbar arteries, and also in the *cervical region* where they come from the occipital artery as its *muscular branches*, the *arteria princeps cervicis* and the *deep cervical artery*. The *occipital artery* will be found curving around from the anterior cervical region between the superficial and deep groups of muscle to pierce the fascia between the insertions of the trapezius and the sterno-cleido-mastoid muscles.

Periosteum and Bone Exposed. The muscles, having been separated from the spines and laminae, the periosteum of the occipital bone is stripped up from below, carrying with it the attachment of the muscles inserted into the occiput. This stripping is much more expeditiously performed if the periosteal elevator is pushed from below upward, on account of the fact that all the muscles which are inserted into the occiput pass up from below and their fibers, following the course of the muscle, tend to keep the elevator against the bone.

As the muscles are separated from their attachments externally, search should be made for the mastoid emissary vein which emerges from the interior of the cranium and anastomoses with the superficial veins of the scalp. It is of variable size; at times it is altogether absent, but often may be 3-4 mm. in diameter. It is located usually along the masto-occipital suture, just above the level of the tip of the mastoid process.

Nerves Encountered in the Exposure. The nerves which supply the muscles of the back and the urn-shaped area of skin bounded by the *pari-eto-acromio-trochantero-coccygeal* lines, of which more detailed mention will be made in the discussion of the dermatomic areas, are the *posterior primary divisions of the spinal nerves*. These nerves leave the mixed spinal nerves as they emerge from the intervertebral foramina and pass backward to be distributed to the muscles and skin of the back.

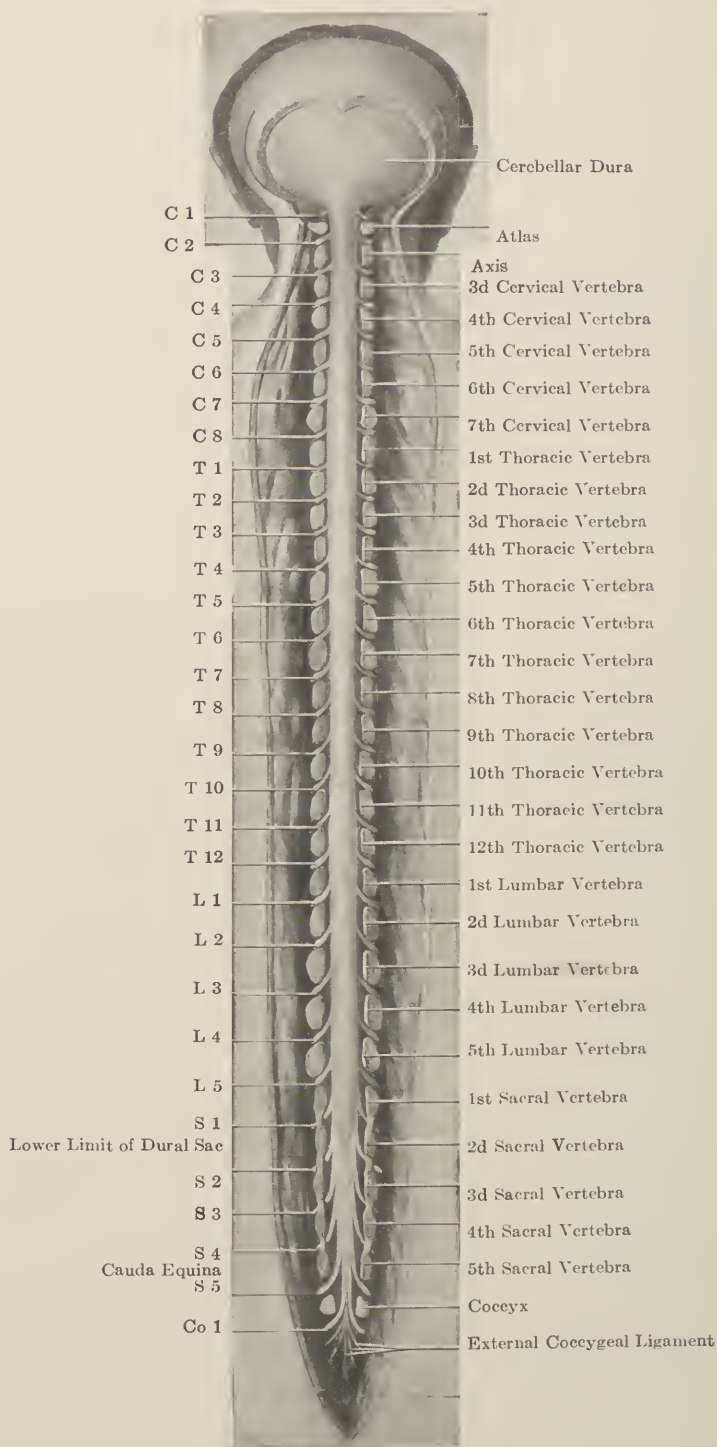


FIG. 98.—Exposure of the dural sac.

In the cervical region, the first three posterior primary divisions have received special names:

1. The first, arising from the first spinal nerve, almost purely muscular, is called the *suboccipital nerve*. It supplies the complexus and the rectus capitis and the obliquus capitis muscles. Since the posterior root of the first cervical nerve is almost regularly lacking, the suboccipital nerve can have no sensory distribution unless it obtains it from a communication with the posterior primary division of the second cervical nerve.

2. The posterior primary division of the second cervical nerve is the *great occipital nerve* and is distributed to the muscles of the neck and the skin over the occiput and upper part of the neck.

3. The posterior primary division of the third cervical nerve, the *smallest occipital nerve*, supplies the muscles of the neck and a small area of skin below that supplied by the great occipital nerve.

The remainder of the posterior primary divisions are not supplied with specific names, but unite irregularly to form the *posterior cervical*, *brachial* and *lumbo-sacral plexus*.

Removal of the Bone. The spines of the vertebræ should now be removed, and this may be most advantageously begun at the fifth lumbar spine. The thick spine is bitten off by means of heavy rongeur forceps close to its base. Angular rongeur forceps can then be inserted, catching the lamina to the right of the base of the spinous process between its jaws. The lamina is then bitten through and the process repeated on the left side of the base of the spinous process. Passing upward, the spines and laminae of the succeeding vertebræ are similarly treated until the entire posterior bony covering of the vertebral canal is removed. This is relatively easy in the lumbar and cervical regions, owing to the fact that there is no overlapping of the spines and laminae. It is somewhat more difficult in the thoracic region, owing to the oblique inclination backward and downward of the dorsal spines, but with a little care the removal may be accomplished without opening the dural sheath.

The laminae should be completely removed in order to provide as much space as is obtainable. In the thoracic region some care will have to be exercised in order that the relatively shallow intervertebral foramina be not encroached upon and the emergent nerve roots damaged.

Exposure of the Dura Mater. The posterior arches of the atlas are similarly divided and the posterior margin of the foramen magnum is exposed.

Attention should be directed toward the removal of the laminae and tubercles on the posterior or dorsal surface of the sacrum. When this is accomplished, the entire vertebral canal lies open, thus exposing the dural sac.

Lying upon the dura, between it and the bony envelope, is found a variable amount of adipose tissue, in which ramify the arteries and veins supplying the membrane. Superiorly the dura is found to be firmly adherent to the foramen magnum; below the foramen magnum the spinal dura is free



FIG. 99.—Dissection showing lateral view of spinal cord and brain with dura mater exposed. (*Bourguery.*)

from the vertebræ and connected to them only by means of delicate fibrous strands.

At the foramen magnum the spinal dura is continuous with the cranial dura, which is intimately adherent to the interior of the cranium especially over the base, at the suture lines and over bony prominences.

At intervals along the sides of the dural sheath, the *spinal nerves* will be seen passing from their points of emergence through the dura to their foramina of exit between the vertebræ. The varying course of these emergent and entrant nerves will be studied in detail when the dura is opened.

Emergence of the Spinal Nerve Roots.

LENGTH OF THE NERVE ROOTS. The course of the mixed nerves from points of origin in the cord to points of emergence through the intervertebral foramina is mainly intradural; but since they do not leave the dural sac exactly opposite the foramina which are to transmit them, they have an intraspinal course which is variable in length. The distance between the point of emergence from the dura and the intervertebral foramina is not the same at all levels, being short in the cervical region and increasing in length from above downward. In the upper thoracic region, this distance is shorter than in the lower cervical region, but as the thoracic, lumbar and sacral regions are reached, the distance becomes greater.

RELATIONS OF DURA TO ROOTS. At the point of passage through the dura in the cervical region, the nerve presents a gentle curve with its concavity upward; in the thoracic region this curve becomes rather a sharp angulation which, on passing downward, is gradually straightened out until in the lumbar region the extradural course is a direct prolongation of the intradural course of the nerve. The dura, as each spinal nerve pierces it, sends out a tubular prolongation surrounding the nerve, which becomes firmly adherent to the nerve just beyond the dorsal root ganglia of the dorsal root as it lies in the intervertebral foramen.

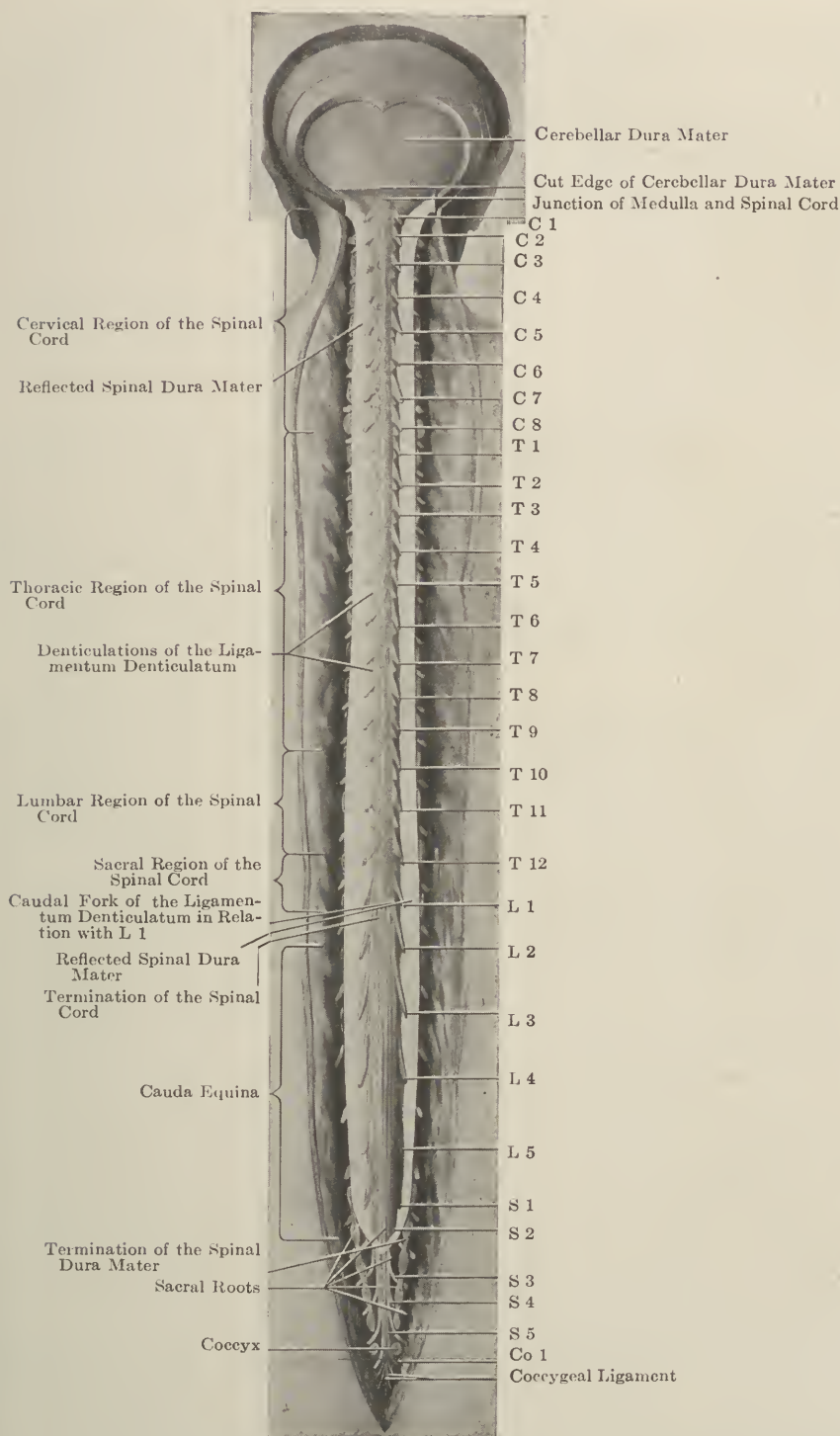


FIG. 100.—Exposure of the dorsal surface of the spinal cord, showing the radicular fans, nerve roots, ligamentum denticulatum and cauda equina.

Arteries of the Vertebral Canal. The arteries of the vertebral canal are derived from the vertebral arteries in the cervical region, from the intercostal arteries in the thoracic region, and in the lumbar region from the four lumbar arteries which are derivatives of the parietal supply of the abdominal aorta. In the sacral region they arise from the middle sacral artery, a branch of the aorta. From these arteries small branches are given off which pass through the intervertebral foramina and divide into branches which supply the spinal cord and the vertebræ.

These vertebral vessels divide into ascending and descending branches which by anastomosing with similar vessels from above and below, produce a double anastomotic chain lying along the posterior surface of the vertebral bodies close to the base of the pedicle on each side and connected with each other across the median line by anastomotic branches.

The Veins of the Vertebral Canal. The veins of the vertebral canal form a rich plexiform arrangement both without and within the vertebral column. The veins on the outside are arranged in two plexus.

1. The *anterior plexus*, which surrounds the bodies of the vertebræ, forms an external line of venous drainage.

2. The *posterior plexus* surrounds the spines, laminæ and transverse processes of the vertebræ, and may cause troublesome hemorrhage during operative procedures.

These two lines of drainage belong to the dorso-spinal venous system. The venous channels within the vertebral canal are of greater interest and constitute the *meningo-rachidian veins* (plexus venosi vertebrales interni). They consist of two longitudinal plexus, the anterior along the posterior surfaces of the bodies of the vertebræ, the *anterior longitudinal vein*, and the posterior in contact with the laminæ, the *posterior longitudinal vein*. These veins drain the bodies of the vertebræ, the meninges and the epidural fat, form a rich anastomosis across the bodies of the vertebræ and communicate with the vertebral, the intercostal, the lumbar and the middle sacral veins which in turn drain into the superior and inferior vena cava.

Caudal Limit of the Dural Sac. The dural sac extends caudally as far as the second sacral vertebra where it terminates by forming a blind sac. The lower three sacral nerves and the coccygeal nerve all perforate the lower end of this sac and pass to their foramina of exit. The lower end of the dural sac is attached to the lowermost part of the sacrum and the coccyx by small bands of fibrous tissue.

Incision of Dura, Exposing Subdural Space, Arachnoid and Pia Mater. The posterior aspect of the dura may now be opened throughout its entire length by a longitudinal incision, and an investigation of the membranes which surround the cord within the dura can be made.

THE ARACHNOID. The next membrane encountered is the arachnoid. This membrane is a delicate non-vascular tissue which completely surrounds the cord and the brain. It is continuous above with the cranial arachnoid at the foramen magnum. It is in quite close contact with the dura, the space between the dura and the arachnoid being relatively small.

THE SUBDURAL SPACE. The space between the dura mater and the arachnoid is called the subdural space, and is nowhere in communication with the space within the arachnoid. The arachnoid also forms sheaths over the spinal nerves, these sheaths fusing with the spinal nerves over the dorsal root ganglia. The arachnoid may now be torn from the posterior surface of the cord and the pia covering examined.

THE PIA MATER. The pia mater is a delicate, highly vascular membrane which covers and is intimately associated with the cord and its nerves. It dips into the furrows and sulci and carries with it the blood vessels destined for the nourishment of the cord.

The Subarachnoid Space and Spinal Fluid. In the living subject, the subarachnoid space is quite extensive and is filled with the *spinal fluid*. In the cadaver the space will be found empty, the arachnoid collapsed and in contact with the pia mater. This collapse is caused by the rapid absorption by the central nervous system of the spinal fluid after death.

Ligamentum Denticulatum. This structure, considered by some to be the suspensory ligament of the cord, arises at the level of the foramen magnum and continues throughout the length of the cord to end opposite the first lumbar vertebra. At the level of the foramen magnum, the ligament arises as two leaves, one from the anterior half of the edge of the foramen magnum, the other from the posterior half; these approach each other and fuse to form the ligament.

The mesial attachment of the ligament is to the entire length of the cord; laterally its attachment to the dura is not continuous but is effected by a series of denticulations which become incorporated in the dura. There are twenty-one of these processes which alternate with the corresponding spinal nerves, a denticulation being inserted into the dura between each two successive nerves. Between these insertions the ligament presents a gentle curve whose concavity is directed laterad. Mesially the attached portion becomes continuous with the pia and, through the fibrous prolongations of the latter membrane into the substance of the cord, gains an attachment to the cord itself.

CAUDAL FORK OF THE DENTICULATE LIGAMENT. Caudally the ligament ends opposite the first lumbar vertebra in a fork-shaped extremity, the lateral limb of the fork being adherent to the dura, the mesial limb extending along the conus to its tip, where it fuses with its fellow of the opposite side and is continued down over the *filum terminale*, a large part of which it forms. Over the fork of the denticulate ligament passes the dorsal root of the first lumbar nerve to meet its ventral root and thus become the mixed nerve.

This relation is of considerable importance in the surgery of the cord and spinal nerves, for it supplies a reliable guide to the identity of one nerve root with which, as a starting point, it is relatively easy to determine the identity of the nerves above and below.

Examination of the Cord and the Emergent Roots. The adult spinal cord extends from the margin of the foramen magnum to the level of the

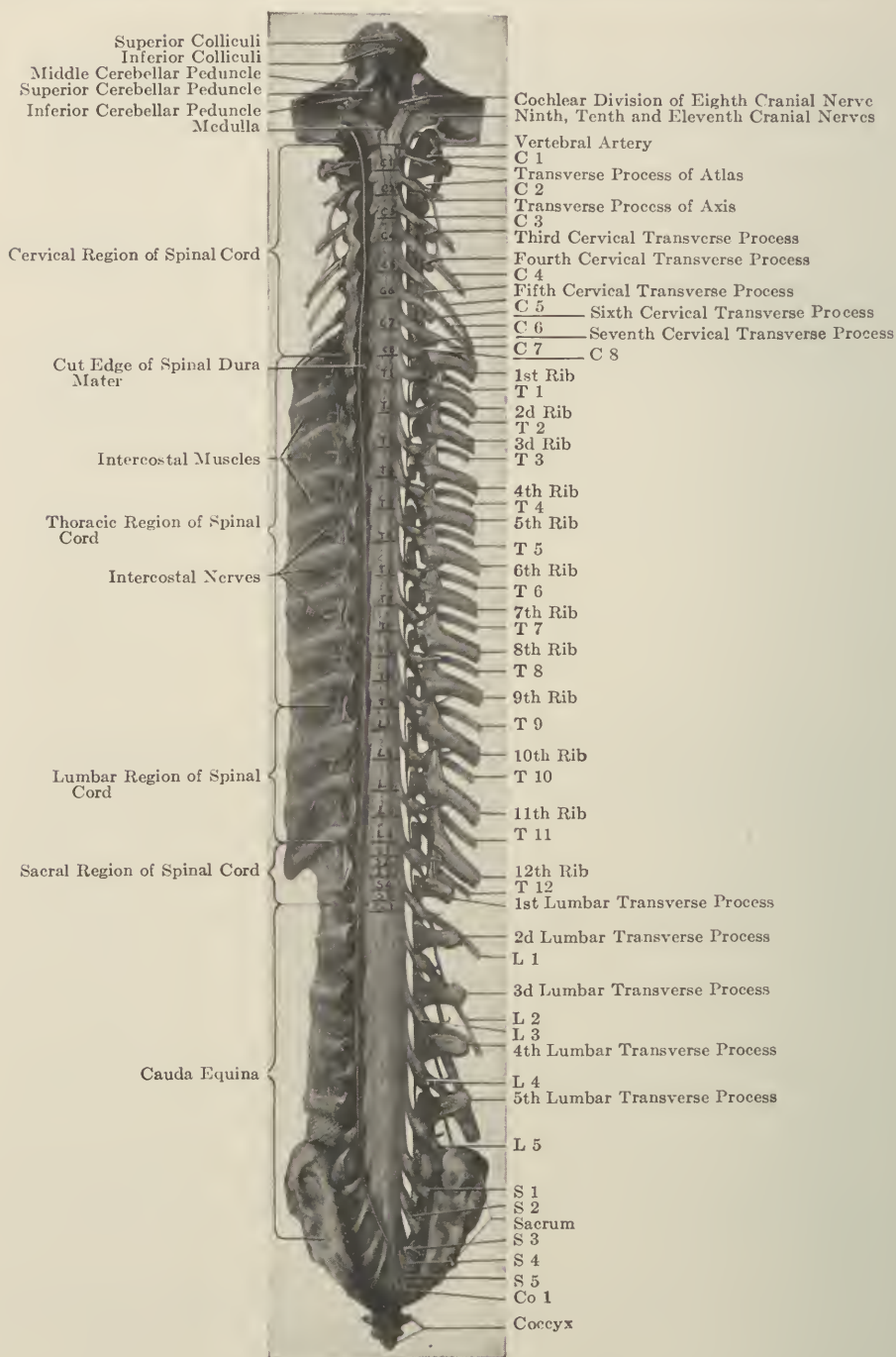


FIG. 101.—Dorsal view of the cerebrospinal axis with the origins of the peripheral nerves and their relations to the vertebral column.

lower border of the first lumbar vertebra or the upper border of the body of the second lumbar vertebra. In two regions there are enlargements mainly in favor of the transverse diameter.

LOCATION OF CERVICAL ENLARGEMENT. The upper enlargement is in the cervical region and is located between the third cervical and second thoracic vertebræ, its maximum being *opposite the fifth or sixth cervical vertebra*. This enlargement is produced by the development within the gray matter of the cord of the large collections of cells which are destined to control the muscles of the upper extremity, and from it arise the 5th, 6th, 7th and 8th cervical nerves and the first two thoracic nerves. The enlargement is called the *cervical enlargement* or the *intumescentia cervicalis*.

LOCATION OF THE LUMBAR ENLARGEMENT. The second enlargement begins about the level of the 10th thoracic vertebra, reaches its maximum development opposite the 12th thoracic vertebra and then tapers gradually away into the *conus medullaris* and the tip called the *epiconus*. From this enlargement take origin the nerves destined for the supply of the lower limb, including the 3rd, 4th and 5th lumbar and the 1st, 2nd and 3rd sacral nerves. The lumbar enlargement is also called the *intumescentia lumbalis*.

RELATIONS OF THE SPINAL CORD AND NERVES IN SITU. The numbering of the nerves in relation to the vertebral foramina through which they pass shows some variations. This is due to the fact that in the cervical region there are eight cervical nerves, whereas there are but seven cervical vertebræ. The first cervical nerve emerges from the vertebral canal above the atlas between it and the occiput, hence the cervical nerves are numbered in relation to the succeeding vertebræ except the eighth, which emerges above the first thoracic vertebra. The thoracic nerves are numbered in relation to the preceding vertebræ, the first thoracic nerve emerging below the first thoracic vertebra and the twelfth nerve below the twelfth thoracic vertebra. The lumbar, sacral and coccygeal nerves in like manner are numbered in relation to the vertebra below which they emerge.

RELATION OF ROOT-ORIGIN TO ROOT-FORAMEN. The origin of the nerves from the cord segments to which they belong does not correspond to the vertebra opposite which they lie. Consequent upon the increase in bulk of the lower cervical region, this discrepancy is in large part made up, but in the thoracic, lumbar and sacral regions there is an increasing obliquity in the intravertebral course of the nerves from the level of the second thoracic vertebra downward to the lowermost part of the canal, where the coccygeal nerve, after traversing an intravertebral distance of 28 cm. from its segment of origin, emerges from its foramen.

RELATION OF CORD SEGMENTS TO THE VERTEBRAL COLUMN. The cervical nerve segments correspond roughly with their respective vertebræ.

The *third thoracic segment*, located above its corresponding vertebra, lies opposite the second thoracic vertebra.

The *sixth thoracic segment* corresponds to the body of the fourth thoracic vertebra.

The *ninth thoracic segment* corresponds to the seventh thoracic vertebra.

The *twelfth thoracic segment* corresponds to the body of the ninth thoracic vertebra.

The *five lumbar segments* correspond to the bodies of the 10th, 11th and 12th thoracic vertebrae. The *five sacral segments* and *one coccygeal segment* correspond to the intervertebral disk between the 12th thoracic and 1st lumbar vertebrae and the body of the 1st lumbar vertebra.

In the *cervical region*, the dorsal root of the first cervical nerve may be found to be entirely lacking or represented by a very fine filament. This absence is explained by the fact that the trigeminal nerve has taken over the area supplied by the first cervical nerve.

SPINAL ACCESSORY NERVE. Emerging from the lateral aspect of the cord, between the attachment of the ligamentum denticulatum and the emergence of the dorsal nerve roots, *beginning at the level of the 6th cervical segment*, will be seen a series of nerve fasciculi which form the *spinal portion* of the *spinal accessory nerve*. This line of emergence moves slightly backward as it is traced upward. The fasciculi join and form a nerve trunk which passes cranially between the denticulations of the denticulate ligament and the posterior nerve roots to enter the skull, where it is joined by its accessory portion at the jugular foramen to become the spinal accessory nerve.

Removal of the Cord. Before the cord is removed from the vertebral canal, its relations to the medulla should be examined. On the posterior surface, it will be observed that the grooves found on the cord are continued on the surface of the medulla. The dorsal sulcus remains as before, except that as it is traced upward it becomes somewhat more pronounced. The dorso-lateral sulcus also remains, but begins to show a tendency to diverge toward the lateral surface. The areas between the dorso-median sulcus and the dorso-lateral sulcus and that external to the dorso-lateral sulcus begin to show a greater prominence.

The cord should now be cut through opposite the margin of the foramen magnum and each pair of spinal nerves should be divided as close to the dural foramina as possible. The denticulations of the denticulate ligament should be divided and the cord lifted out of its bed in the dura.

CHAPTER VII

THE SPINAL CORD

· ITS GENERAL CHARACTER AND ANATOMY

Form of the Spinal Cord. The spinal cord is a long cylindrical structure occupying the greater portion of the vertebral canal and extending from the border of the foramen magnum in the skull to the lower border of the first lumbar vertebra. Although generally cylindrical in form, it presents considerable ventro-dorsal flattening, and in certain areas its diameters are greater than in the regions immediately above and below. These areas are spoken of as the spinal cord enlargements, of which there are two, one in the cervical region, the *cervical enlargement* (*intumescencia cervicalis*), and one in the lumbar region, the *lumbar enlargement* (*intumescencia lumbalis*). At its caudal extremity, the spinal cord tapers and ends in a slender filament, the *filum terminale*, or *central ligament* of the spinal cord.

Regional Differences in the Spinal Cord. When stripped of its surrounding pia mater the cord appears glistening and white. Its consistency is firm, although it readily yields to pressure and becomes distorted. This fact is of practical importance, since it indicates the necessity for delicacy in surgical manipulation. It is possible to distinguish certain regions in the spinal cord because of the presence of the two enlargements already mentioned. These regions, enumerated from the upper portion of the spinal canal toward the coccyx, are: (1) The cervical region; (2) the thoracic region; (3) the lumbosacral region; (4) the conus terminalis, and (5) the *filum terminale*.

Significance of the Several Regions of the Spinal Cord. The cervical enlargement develops in consequence of the increased demand for innervation by the upper extremities; and in like manner the lumbar enlargement appears in response to the demand for greater nerve supply to the lower extremities. This fact is demonstrated by embryology and also by comparative anatomy. It has been shown that in the early stages of development, before the limbs make their appearance, the spinal cord is completely cylindrical from its cephalic to its caudal extremity. As soon as the limbs are developed, however, the two enlargements make their appearance and thus provide the greater number of nerve cells for the regulation of the movements of the extremities. Comparative anatomy confirms these observations, since it has been shown that in the animal series the two enlargements of the spinal cord bear a constant relation in their dimensions to the size and purposes of the extremities. Both enlargements are well marked in the bipeds in which, as in man and the anthropoid apes, they reach considerable dimensions. On the other hand, the enlargements may be much reduced in size in animals which have rudimentary extremities. The lumbar enlargement, for example

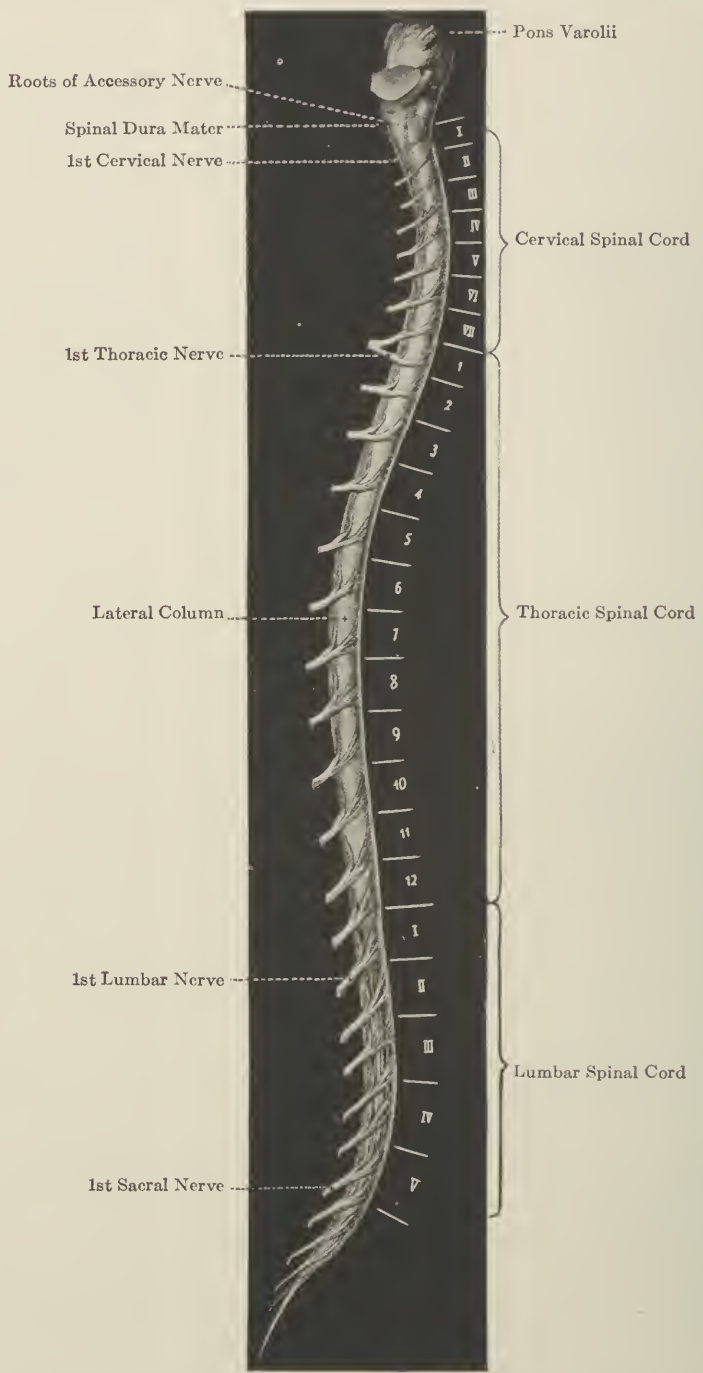


FIG. 102.—Spinal cord viewed from the right. (*Spalteholz.*)

is small in the aquatic mammals, such as the seal and the cetacea, the cervical enlargement, similarly, is small in the marsupials, such as the kangaroo, while both enlargements are absent in animals which have no extremities, such as the serpents. The portion of the cord intervening between the cervical and lumbar enlargements is relatively small in its diameters, because the musculature which it controls is not only less extensive but less capable of complex activities. The tapered portion forming the *conus terminalis* is representative of a region in the body much less extensive in its executive organs and receptors than other parts.

Dimensions and Weight. The spinal cord in the adult male varies from 43 to 45 centimeters in length or about 17 to 18 inches. It is somewhat shorter in the female.

Its circumference in the	{	cervical enlargement is.....	38 mm.
		lumbar enlargement.....	33 mm.
		intermediate portion.....	27 mm.
Its transverse diameter in the	{	cervical enlargement is.....	13 mm.
		lumbar enlargement.....	12 mm.
		intermediate portion.....	10 mm.
The antero-posterior diameter of the	{	cervical enlargement is.....	9 mm.
		lumbar enlargement.....	9 mm.
		intermediate portion.....	8 mm.
The length of the filum terminale is from 17 to 18 cm.			

Freed of its membranes and detached from its nerve roots, the spinal cord weighs from 26 to 30 grams in males and 1 or 2 grams less in females. At birth the weight of the spinal cord in proportion to that of the brain is 1 to 100, while in the adult the ratio of spinal cord to brain is 1 to 50. The main increase occurs in the first two years of life. The weight of the spinal cord in the new-born is 3 to 4 grams and the average length is 14 centimeters. At birth the length of the body bears the proportion to the spinal cord of 10 to 3; at the end of the first year this ratio has changed to 12 to 3, while in adult life in the average male of six feet in height, this same proportion is maintained. The relative weights of the different portions of the central nervous system are as follows:

Spinal cord.....	30 grams
Medulla oblongata, pons and midbrain.....	26 grams
Cerebellum.....	140 grams
Cerebral hemispheres.....	1170 grams
Entire brain.....	1366 grams

On the basis of these figures it is apparent that the combined weight of the medulla oblongata, pons and midbrain is about equivalent to that of the spinal cord. The cerebellum is five times as heavy as the spinal cord and the cerebral hemispheres about forty times as heavy.

The density of the	{	gray matter of the spinal cord is.....	1.0382
		white matter of the spinal cord is.....	1.244
		cord as a whole in males is.....	1.387
		cord as a whole in females is.....	1.348

General Relations. The spinal cord adapts itself to the flexures of the vertebral column, and presents in consequence two large curvatures. One curvature is situated in the cervical region with its concavity facing dorsally. The second and longer curvature is in relation with the thoracic portion of the cord, the concavity of which is directed ventrally. The spinal cord occupies the center of the vertebral canal, but because this canal has greater diameters than the cord, there exists a perineural space of considerable size. In this space are contained the meninges or coverings of the spinal cord, together with the cerebrospinal fluid. The inner bony surface of the vertebral canal is covered by ligamentous processes entering into the vertebral articulations, in addition to a semi-fluid fatty substance situated between these ligamentous processes and the outer surface of the dura mater.

Means of Fixation. The spinal cord is more or less firmly fixed in the spinal canal and is almost, if not quite, immobile. It owes this fixity to several structures which attach it to the bony wall, or suspend it from above.

At its superior extremity, its continuity with the brain in the region where it passes over into the medulla oblongata affords the means for its suspension.

Its inferior extremity is attached by means of a prolongation from the dura mater known as the *coccygeal ligament* of the spinal cord. This envelops the filum terminale and descends with the latter into the sacral canal where it becomes attached to the base of the coccyx.

Throughout its entire length from the atlas to the first lumbar vertebra, the cord is fixed to the inner surface of the dura mater, which latter is itself attached to the bony canal by means of the fibrous sheaths upon the spinal nerves. Certain connective tissue processes supplement this attachment. The more important of these are a system of filiform prolongations irregularly disposed upon the anterior and posterior surfaces. Another set of more regular filiform prolongations of connective tissue, one on the right and the other on the left, constitute the *denticulate ligament* (ligamentum denticulatum) and form a pair of ligamentous supports which serve to hold the spinal cord in place.

Surface Markings. When the membranes surrounding the spinal cord are removed and its nerve roots are detached, certain markings may be seen upon the surface which are of much significance. For purposes of description, the circumference of the cord may be divided into a *ventral*, a *dorsal* and two *lateral surfaces*.

The Several Surfaces of the Cord. **THE VENTRAL SURFACE.** In the midventral line, extending from the cephalic extremity to the conus terminalis, there is a deep and straight sulcus having such a position as to divide this surface of the cord into two equal halves, one upon the right and the other upon the left. This sulcus indicates the presence of a deep fissure which extends dorsally toward the gray matter of the cord and affords the means by which the chief blood vessels supplying the more ventral regions make their way into the spinal cord substance. This is the *ventro-median fissure*. When separated this fissure will be seen

to extend inward to a depth of from 2 to 3 millimeters and to end in relation with a band of glistening white fibers which constitutes the *ventral white commissure* of the cord.

Upon either side of the ventro-median fissure, and at a distance of about 3 millimeters, is a shallow groove, somewhat irregular in outline, but extending the entire length of the spinal cord. This, unlike the ventro-median fissure, is superficial and in places seems to fade out altogether. It is the *ventro-lateral sulcus* and derives its importance from the fact that it marks the area upon the surface of the cord from which the *ventral* or *motor spinal roots* make their emergence as they pass to their exit through the intervertebral foramina.

Situated between the ventro-median and ventro-lateral sulci is a long region upon the ventral surface of the cord known as the *ventral column*. This column in its more cephalic portion is often subdivided into two fasciculi by a long, shallow sulcus known as the *ventral paramedian sulcus*. The sulcus is most conspicuous in the cervical region of the cord, and may be traced into the medulla oblongata where it assumes still greater prominence.

THE DORSAL SURFACE. This surface presents many features similar to those of the ventral surface. A long groove, extending from the cephalic to the caudal end, terminates in the conus terminalis. This is the *dorso-median sulcus*. It differs from the ventro-median sulcus because of its shallowness. In place of such a fissure, there is a wide septum of connective tissue which serves to hold together the two dorsal portions of the spinal cord. This is the *dorso-median septum*. The dorso-median septum penetrates somewhat closer to the gray matter than is the case with the ventro-median fissure, so that the internal extremity of the septum

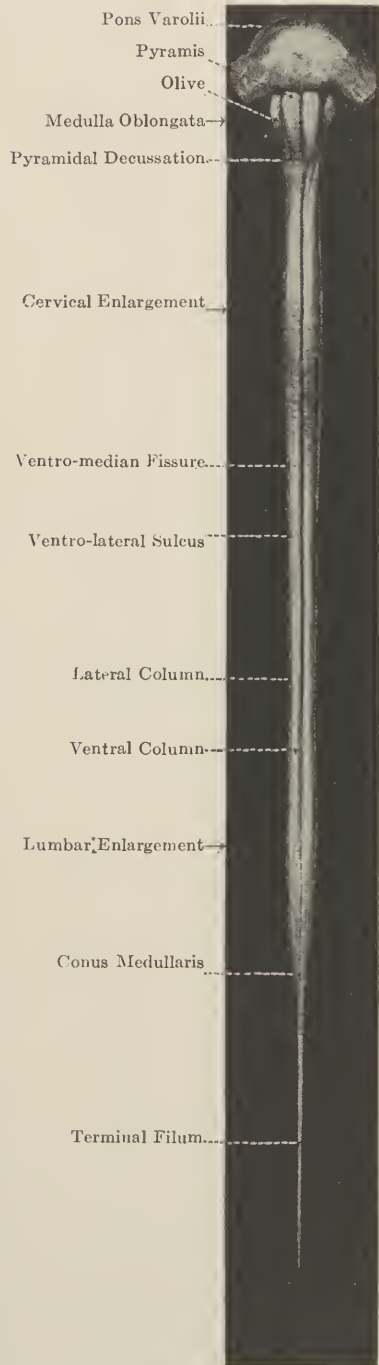


FIG. 103.—Spinal cord viewed from in front (nerve roots not shown). (Spalteholz.)

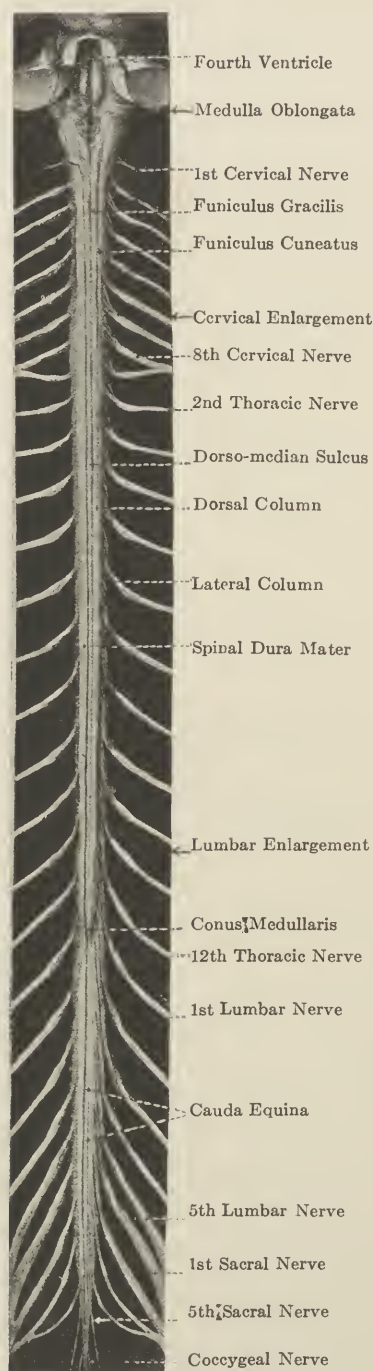


FIG. 104.—Spinal cord viewed from behind. (*Spalteholz*.)

is in actual contact with the gray commissure of the cord. Upon either side of the dorso-median sulcus, at a distance of 3 millimeters, is another broad and shallow longitudinal sulcus. This is the *dorso-lateral sulcus*. It marks the position in which the dorsal root fibers come in contact with and enter the spinal cord.

The surface area comprised between the dorso-median and dorso-lateral sulci is the *dorsal column* of the cord. In the cervical region, this column is still further subdivided by the appearance of a shallow sulcus running parallel to the others and situated about midway between them. This is the *dorsal paramedian sulcus*. It usually disappears below the level of the fourth thoracic segment. Its presence divides the dorsal column into two more or less equal secondary fasciculi, one lying mesially and the other laterally. The more mesial of these two fasciculi is the *fasciculus* or *column of Goll*, while the more lateral one is the *fasciculus* or *column of Burdach*.

THE LATERAL SURFACES. These two surfaces, one upon either side, are included between the ventro-lateral and the dorso-lateral sulci respectively, and constitute an extensive field upon the lateral aspect of the spinal cord, the *lateral column*. In specimens showing the nerve roots still in position, it will be seen that this area lies between the ventral and dorsal nerve roots. A longitudinal line at approximately the middle of this lateral surface gives attachment, from the atlas downward as far as the first lumbar vertebra, to the mesial border of the *ligamentum denticulatum*.

The *sulcus intermedius* is an ill-defined groove appearing upon the lateral surface. It is fairly well marked in the lumbar region where it is situated immediately ventral to the eminence produced by the large dorsal gray column. It is faintly marked in the thoracic segments, but in the upper cervical portion of the cord

becomes most pronounced and continues cranially onto the medulla. It gains prominence through the emergence of the spinal portion of the spinal accessory nerve.

The spinal cord is almost completely divided into two equal halves by the ventro-median sulcus and dorso-median septum. Each half represents the corresponding half of the body. Ventrally the division is quite complete as far as the white commissure; dorsally, the two halves of the cord are held together by the septum as by a seam. Upon its surface each half of the cord presents three fields or columns: (1) A ventral column, limited mesially by the ventro-median sulcus and laterally by the ventral root fibers; (2) a dorsal column, limited mesially by the dorso-median sulcus and laterally by the dorsal root fibers; (3) a lateral column comprised between the ventral and dorsal root fibers.

The Roots or Radicles of the Spinal Nerves. Each half of the spinal cord is connected with the periphery by means of two sets of nerve roots or radicles. One set of these roots appears at the junction of the ventral and lateral columns. These are the *ventral roots*. The second set makes its appearance at the junction of the dorsal and lateral columns. These are the *dorsal roots*. The sulci already referred to as the ventro-lateral and the dorso-lateral sulci constitute a more or less unbroken line extending from the cephalic to the caudal extremity of the cord. From the ventro-lateral sulcus nerve fibers are constantly making their emergence from the cord along its entire length. Similarly, nerve fibers constantly make their entrance into the spinal cord along the line of the dorso-lateral sulcus. The spinal cord as a whole, therefore, is in connection with four sets of nerve fibers; two upon the right side and two upon the left. Although they make a continuous line in their connection with the cord, these fibers are so aggregated that, when they come into relation with the bony wall of the spinal canal, they give rise to collected bundles of nerve fibers, *the spinal nerves*. The nerve fibers in connection with the spinal cord are collected to form fine root filaments arranged in serial order. These are the *fila radicularia*. The root filaments tend to arrange themselves in groups, so that five or ten of them become gathered into a strand as they come into relation with the bony wall of the spinal canal. In this manner each series of root filaments constitutes a *radicular* or *root fan*, the constricted portion or the handle of which is situated in the intervertebral foramen. This handle forms the *radicular fasciculus* or *root strand* of the spinal nerve. As a result of this arrangement, the dorsal and ventral aspects of the spinal cord present a reg-

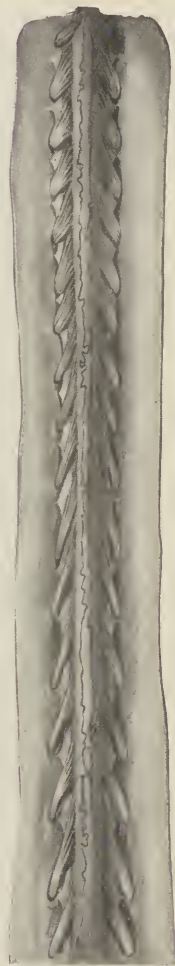


FIG. 105.—The cervical and thoracic cord from behind. (Elsberg.)

ular series of these radicular fans constituting the ventral and dorsal roots respectively. After its confluence to form the *root strand*, each radicular fan of the dorsal series unites with the corresponding radicular fan of the ventral series to form a *mixed nerve*. This junction is accomplished in or near the intervertebral foramen, in which position an enlargement occurs on the

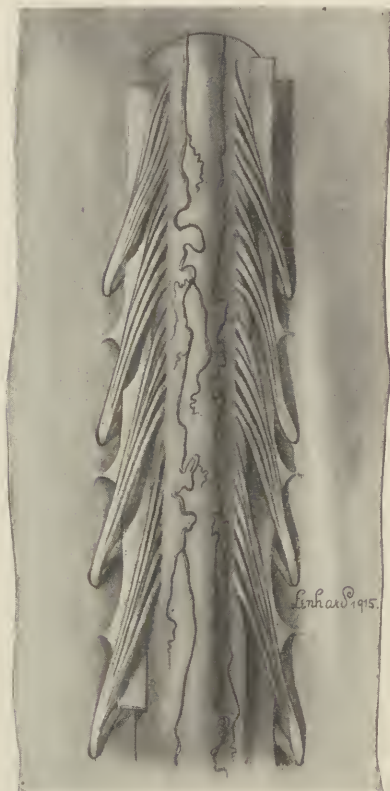


FIG. 106.—The relation of the dentate ligament to the cord and the dorsal roots. (Elsberg.)



FIG. 107.—The "fork" of the dentate ligament, and its relation to the first lumbar root. On the right side the roots have been cut to show the shape of the fork. (Elsberg.)

dorsal root fibers, the *dorsal root ganglion*. Each typical spinal nerve is, therefore, made up by the confluence of dorsal and ventral root fibers as they approach the intervertebral foramen.

There are in all 31 pairs of spinal nerve roots, 8 in the cervical region, 12 in the thoracic region, 5 in the lumbar region, 5 in the sacral region, and 1 in the coccygeal region.

Sometimes an additional coccygeal nerve root is present, while the vestiges of a third pair of coccygeal nerve roots are occasionally found in the bundles of medullated fibers contained in the filum terminale. In some in-

stances the coccygeal nerve is entirely absent or only a few fibers representing its vestigial remains appear incorporated in the filum.

It is customary in the thoracic, lumbar and sacral regions to enumerate the nerve root by giving it the number of the vertebra below which it emerges. The eight pairs of cervical nerve roots outnumber by one the cervical vertebræ. This is due to the fact that the most cephalic cervical nerve is placed above the atlas, while the second and each succeeding cervical nerve root emerges below the vertebral body with which its spinal segment is in relation. The first of the eight cervical roots is also called the *suboccipital nerve*. The root of the first coccygeal nerve emerges from the lower end of the sacral canal and then passes below the first vertebral segment of the coccyx. With the exception of the first cervical or suboccipital nerve, all of the spinal nerve roots emerge from the vertebral canal through intervertebral foramina.

In the intravertebral portion of their course, the nerve fibers of the spinal nerve roots are ensheathed by the three coverings of the spinal cord. The pia mater extends out upon the fila radicularia. At the point where the radicular strands of the dorsal and ventral roots join, the arachnoid and dura mater ensheath the nerve root and form a covering about it as the fibers pass through the intervertebral foramen. In this portion of its course the nerve root and its ganglion are ensheathed by the dura.

Differences in the Root Fibers. Certain differences are to be noted in the nerve fibers entering into the ventral and dorsal nerve roots. The fibers in the dorsal roots are distinguished by their greater size and the larger number of filaments entering into the root fan. The prominent distinguishing feature of the dorsal root is the connection with it of the dorsal root ganglion. The root ganglia are usually found in the intervertebral foramina immediately beyond the point at which the dura mater begins to form a sheath about the nerve roots. The first and second cervical ganglia, however, lie upon the neural arches of the vertebræ, while the ganglia of all the sacral nerves are contained in the vertebral canal itself. The dorsal root ganglion of the coccygeal nerve lies in the canal within a sac of the dura mater and usually at a distance from the origin of the nerve. The filaments forming the root fans of the dorsal root fibers are usually collected into two bundles as they approach the ganglion, which is bifurcated to receive them.

Certain variations in the nerve roots are of importance. The dorsal

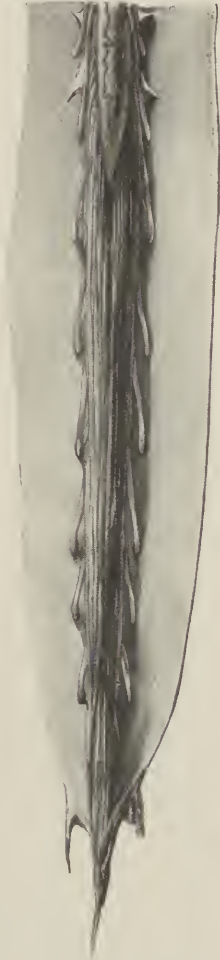


FIG. 108.—The lumbo-sacral cord and cauda equina. (Elsberg.)

root of the first cervical nerve is often absent. Frequently one or more of the nerve roots of the thoracic region is wanting. In some cases small detached portions of the dorsal

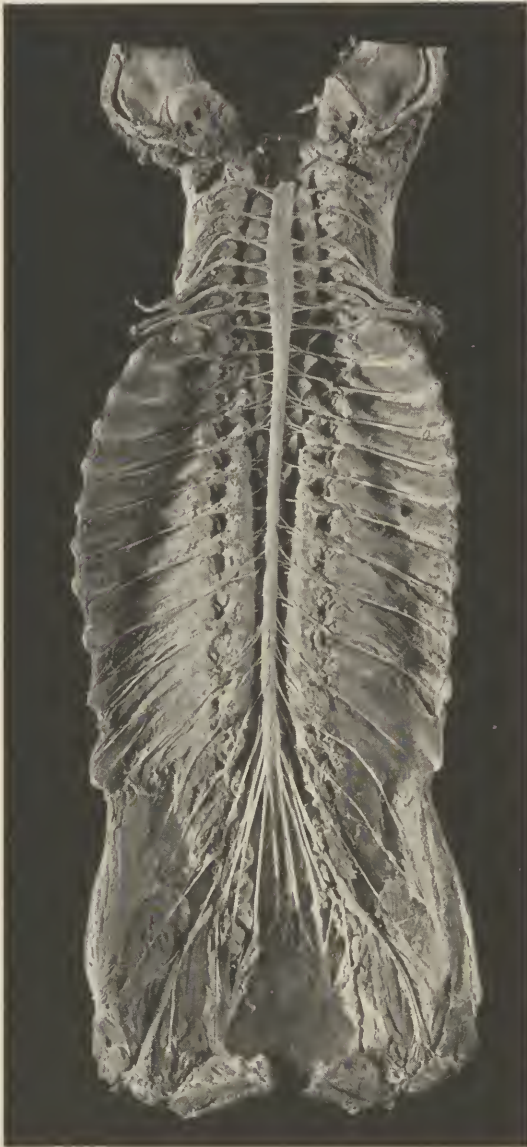


FIG. 109.—Dissection of a six months human fetus showing a ventral view of the spinal cord, the spinal nerves and the nerve roots. (Huntington.)

root ganglia, the so-called *ganglia aberrantes* of Hyrtl, are found in connection with the dorsal roots of the upper cervical nerves. The ganglia of the lumbar and upper sacral nerves are sometimes double, while the dorsal root ganglion of the suboccipital nerve may lie within the dural sheath or be altogether wanting.

Length and Direction of the Spinal Roots. The distance between the point of emergence from the spinal cord and the intervertebral foramina of the cervical region is relatively short, and hence the cervical roots of the spinal nerves are shorter than any of the others. Each successive nerve root in proceeding down the column increases gradually in length from nerve to nerve, so that while the lower cervical nerves correspond in length to the height of at least one vertebra, that of the lower thoracic nerves is equal to the height of two or three vertebrae. From the fact that the spinal cord comes to an end at the lower border of the body of the first lumbar vertebra, it will be seen that the length of the roots of the lumbar, sacral and coccygeal nerves must each in succession be increased by the height of one vertebra. The five

lumbar nerve roots descend in the vertebral canal from their point of emergence from the spinal cord to the intervertebral foramina, a distance corresponding to the height of four to six vertebrae. The lower lumbar roots

make a long descent in their course through the vertebral canal. The five sacral nerves descend in the canal from their point of emergence from the spinal cord to their respective intervertebral foramina, a distance measured by the height of five to eleven vertebral bodies, while the descent of the coccygeal nerve corresponds to the height of twelve vertebral bodies. Because of this arrangement, the nerve root fibers connected with the lower portion of the cord become longer the lower their point of connection. Their collected mass filling the lower portion of the vertebral canal constitutes a structure, which, because of its resemblance to the tail of a horse, is called the *cauda equina*. The following table shows the respective lengths of the nerve roots in an eighteen-year old subject whose spinal cord was forty-one centimeters long (according to Testut):

Nerve	Right side, mm.	Left side, mm.
Third cervical.....	18	17
Fifth cervical.....	25	25
First thoracic.....	33	32
Fifth thoracic.....	47	47
Tenth thoracic.....	68	68
Twelfth thoracic.....	111	110
First lumbar.....	114	114
Second lumbar.....	138	134
Third lumbar.....	151	151
Fourth lumbar.....	163	164
Fifth lumbar.....	181	180
First sacral.....	188	188
Fifth sacral.....	280	280

The first cervical nerve is directed horizontally outward, while the roots of the lower cervical and thoracic nerves descend for a short distance along the spinal cord, being held in contact with it by means of the arachnoid. At the point where they approach the several foramina through which they make their exit, they extend directly outward in a horizontal direction. All of the nerve roots constituting the *cauda equina* run for a considerable distance downward from the end of the spinal cord toward their respective foramina of transmission.

Relation of the Spinal Cord to the Spinal Column. For the general purposes of localization, it should be remembered that the cervical enlargement corresponds in extent to the portion of the vertebral column which includes the 3d, 4th, 5th, 6th and 7th cervical and the 1st and 2d thoracic vertebræ. The lumbar enlargement occupies a similar relation to the spines of the 10th, 11th and 12th thoracic vertebræ. The *cornu terminalis* is in relation with the body of the 1st lumbar vertebra, while the part situated between the 2d thoracic and the upper border of the 10th thoracic vertebræ is the thoracic portion of the spinal cord.

The upper limit of the spinal cord is determined by a horizontal plane passed through the articulation of the atlas and the condyles of the occipital bone. The caudal limit of the cord extends to a plane passed horizontally through the lower margin of the body of the first lumbar vertebra. In some

cases this extends somewhat further caudally and is marked by the plane passing through the upper border of the second lumbar vertebra.

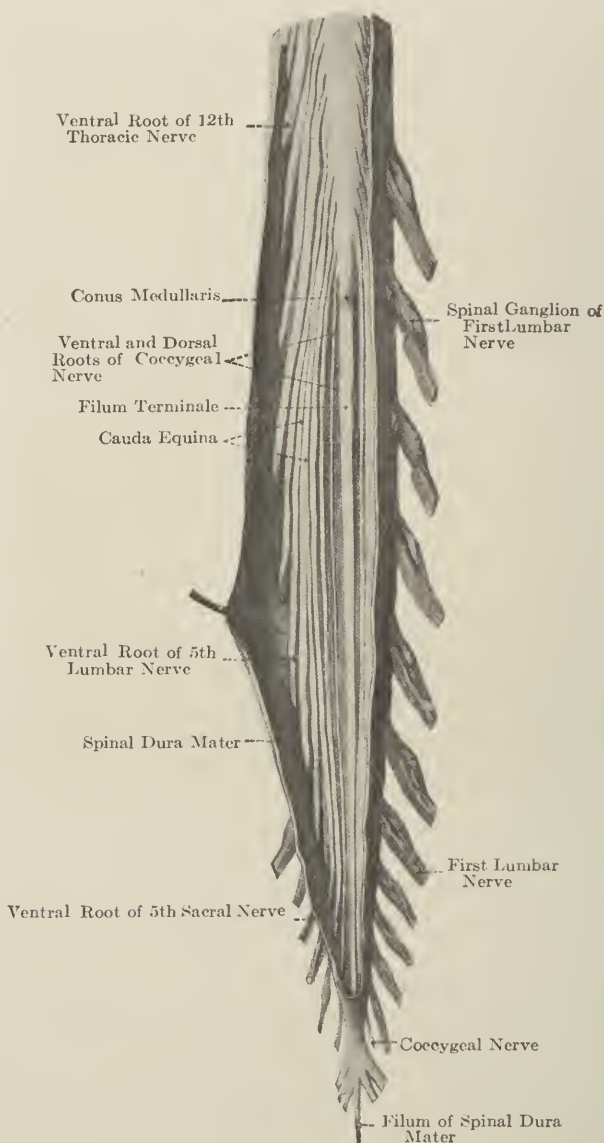


FIG. 110.—Lower end of spinal cord with nerve roots, from in front. (The dura mater has been opened and drawn to the right side; the arachnoid has been removed. On the left side pieces have been cut out of the anterior roots of the 1st and 2nd lumbar nerves.) (*Spalteholz*.)

The relations of the caudal extremity of the spinal cord vary considerably according to the age of the individual. In the new-born the spinal cord extends to the third lumbar or even to the fourth lumbar vertebra. In the

sixth month of intra-uterine life the tip of the conus terminalis corresponds to the base of the sacrum, while in the third fetal month the cord occupies



FIG. 111.—The extent of the spinal cord of the fetus at the fifth month. (Compare with Fig. 112.) (*Elsberg.*)

the entire length of the vertebral canal and descends as far as the base of the coccyx. During the several stages of development the spinal cord seems to ascend in the vertebral canal in such a way that the tip of the conus terminalis loses its original relation with the coccyx. It gradually assumes a position higher in the canal and finally attains its adult relation with the lower border of the first lumbar vertebra. This movement of ascension on the part of the cord is apparent and not real. It is due to a disparity in growth between the vertebral column and the cord. The result of this disparity is a seeming upward shift of the conus terminalis. During this change in relations, the nerve roots of the lumbar, sacral and coccygeal segments become greatly elongated in order that they may retain their original connection with the cord and at the same time make their emergence from their proper intervertebral foramina. Two important features develop in consequence of the disparity in growth between cord and column: (1) The caudal portion of the vertebral canal which in fetal life contains the spinal cord no longer does so in the adult. (2) This caudal portion of the canal in the

adult contains the elongated root fibers connected with the lumbar, sacral and coccygeal segments of the spinal cord, which make their emergence through the intervertebral foramina of the lumbar, sacral and coccygeal portions of the column. Their collected fibers constitute the *cauda equina*.



FIG. 112.—The extent of the spinal cord in the adult, ending at the first lumbar vertebra. (*Elsberg.*)

The apparent ascension of the spinal cord in the vertebral canal during the course of development also explains the obliquity of the root fibers, not only in the thoracic but in the cervical nerve roots as well.

CHAPTER VIII

THE SPINAL CORD

ITS COVERINGS AND CIRCULATION

The Osseous Covering. The spinal cord is encapsulated and protected by a series of envelopes. The outermost of these, the bony envelope, is constituted by the vertebral segments which go to make up the vertebral column. This bony envelope is reenforced upon the dorsal aspect of the body by large and powerful groups of muscles, in addition to fascial planes and ligamentous processes of unusual strength. The vertebral canal in which the spinal cord is lodged is made up of the articulated series of the vertebræ, so placed that the vertebral body lies ventral to the spinal cord whose lateral aspects and dorsal surface are concealed beneath the neural arches. The arches consist of the pedicles, laminæ and spinous processes. The vertebral column and muscles attached to it form a covering of great protective value against the usual stresses to which the spinal cord is subjected. They also form a flexible encasement, so that many movements of the body involving flexion, rotation and gliding of the vertebral bodies may be produced without injury to the cord.

Although the bony capsule surrounding the spinal cord affords adequate protection against usual strain, the nature of the canal and its bony character make the spinal cord peculiarly liable to serious damage from unusual strain. The cord under certain conditions, being held in a fixed position, has no chance of escape and must bear the full brunt of injury due to dislocation or fracture of its bony envelope. While the vertebral column, therefore, affords excellent protection against ordinary stress, it becomes an actual disadvantage to the spinal cord in the event of severer injury.

Within the bony capsule there is a series of envelopes of equal importance. The outermost of these is the *dura mater*, or *pachymeninx*. The second membranous envelope is the *arachnoid*. The third envelope is unlike the others; it consists of a transparent liquid, the *cerebrospinal fluid*, which surrounds the spinal cord like a water jacket. The fourth and innermost capsule is a delicate, vascular membrane, the *pia mater*, also known as the *leptomeninges*.

Spinal Dura Mater. In its general outlines, the dura mater presents itself as a cylindrical tube lying within the vertebral canal and extending from a firm attachment to the border of the foramen magnum as far caudally as the second or third sacral vertebra.

The dura mater does not come in direct contact with the inner surface of the bony canal, there being a considerable space between it and the outer surface of the spinal cord. The space between the dura mater and the bony

wall of the vertebral canal, called the *supradural space* contains a semifluid, fatty substance.

The *external surface* of the dura mater is traversed by many large venous channels. Dorsally it is almost entirely free of any connection with the inner surface of the vertebral canal. Ventrally, however, it is attached to the common posterior vertebral ligament by a system of fibrous prolongations which

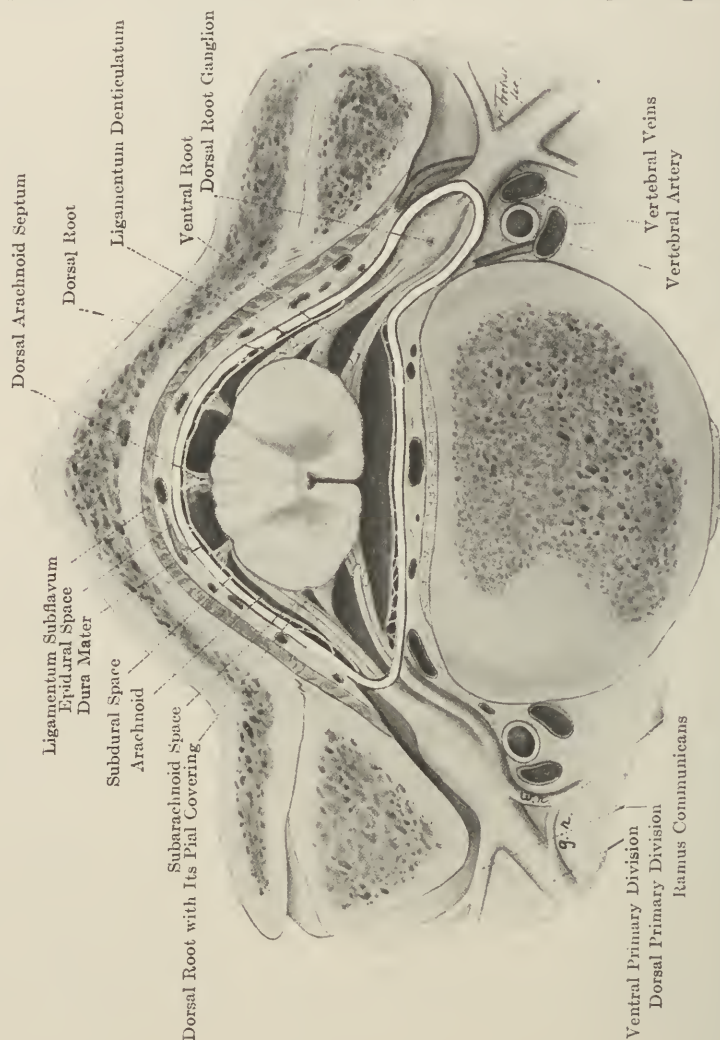


FIG. 113.—Cross section of the spinal cord, the nerve roots and the coverings of the spinal cord.
g. r.—Gray ramus communicans; w. r.—White ramus communicans. (Raubert.)

are most pronounced in the cervical and lumbo-sacral regions, and most feebly developed in the thoracic region. From its lateral aspects the dura mater gives off a series of neural prolongations or sheaths, which envelop the spinal nerves and accompany the latter as far as their point of exit from the intervertebral foramen. Each spinal root at its point of entrance into the intervertebral foramen receives a special, separate investment from the dura. The ventral and dorsal root strands as they approach their confluence

are encased in a separate dural sheath as far out as the external extremity of the spinal root ganglion. When the actual junction between the dorsal and ventral root strands occurs, the two separate sheaths of dura merge, and the mixed nerve is then surrounded by a common dural sheath. The root strands, the dorsal root ganglia and the mixed nerve are firmly fixed in the intervertebral foramen by connective tissue processes attached to the bone and to the dura.

The *internal surface* of the dura mater is opposed to the external surface of the arachnoid, with which it is in intimate connection. The arachnoid is adherent to the inner surface of the dura mater by means of a number of connective tissue prolongations. Along the longitudinal line determined by the points at which the nerve roots come into relation with the dura mater the denticulate ligament is attached by means of a series of serrated processes. The attachments of the ligament extend from the cephalic extremity of the spinal canal to the root of the first lumbar nerve. In relation with the attachment line of the denticulate ligament are several small apertures arranged in pairs, marking the point of entrance of the nerve roots into their dural sheaths. Each pair of openings is so arranged that the ventral aperture has a slightly higher plane than the dorsal. These apertures are variable in their disposition and may be separated by one or two millimeters. In some cases, the root strands dip into their neural sheaths through a single aperture in the dura. As a rule, the blood vessels which go to the spinal cord pass through the same orifices with the roots. Exceptionally, however, the blood vessels have independent passageways of their own.

The Upper and Lower Extremities of the Dural Sac. The upper extremity of the dural sac is firmly attached to the margin of the foramen magnum. The lower extremity lies in the sacral canal and contains the fibers which constitute the cauda equina. Caudally, the dural sac terminates in a cone-shaped prolongation at the lower border of the second sacral segment. Its termination is called the *dural cul-de-sac*.

Although the dural sac extends to the lower boundary of the second sacral segment, the dura itself is prolonged downward through the remainder of the sacral canal as separate processes, ensheathing the lower fibers of the cauda equina and forming a covering for the filum terminale. The process of the dura in relation with the filum reaches caudally as far as the dorsal portion of the first coccygeal segment, where it is firmly attached to the bone. This portion of the dura is the *coccygeal ligament* of the spinal cord. In its entire length, the dural cul-de-sac is attached along its ventral surface by means of fibrous prolongations to the dorsal common vertebral ligament. These prolongations are irregularly fenestrated, and constitute the *ventral ligament of the dura mater of Trolard*. Separate prolongations from the cul-de-sac form neural sheaths about the second, third, fourth and fifth sacral nerves and also about the first coccygeal nerve. These sheaths extend from the external surface of the cul-de-sac to the several foramina of emergence of the sacral and coccygeal nerves. The dorsal root ganglia of the first, second and third sacral nerves lie in their dural sheaths immediately external to

the dural cul-de-sac, while the ganglia of the fourth and fifth sacral nerves and the coccygeal nerve lie within the sacral canal at a considerable distance from the cul-de-sac.

Spinal Arachnoid. A second membranous envelope surrounding the spinal cord lies immediately within the dura mater. This is the *arachnoid*. Its outer surface is loosely adherent to the inner surface of the dura, a connection established by fine, filamentous, connective tissue processes. The arachnoid is a membrane without blood vessels, consisting of two laminae which are separated by a narrow cleft, the *arachnoid space*. The outer or parietal layer of the arachnoid is attached to the inner surface of the dura. The inner or visceral layer is a thin and transparent membrane extending the entire length of the cord and for some distance upon the cauda equina. It descends as far as the apex of the dural cul-de-sac, where it is reflected outward to become continuous with the parietal layer. The arachnoid is separated by a spacious cavity from the spinal cord. This is the *subarachnoid space*. Between the visceral and parietal layers of the arachnoid, there is a small interval called the *arachnoid cavity*. This space is traversed by many connective tissue trabeculae which hold the parietal and visceral layers together. The cavity is filled with a serous fluid. The following structures pass through the arachnoid and in their passage receive a serous sheath from it.

1. The dural extremity of the denticulate ligament.
2. The ventral and dorsal root fibers of the spinal nerves.
3. The blood vessels which accompany the roots.

Spinal Pia Mater. The innermost envelope surrounding the cord is intimately attached to that organ and sends many thin septal processes, the *septula*, into the substance of the white matter. It consists of an internal and external layer between which run the many blood vessels supplying the substance of the spinal cord. The internal layer is intimately attached to the cord, both by means of the septula and also by numerous vessels which enter the medullary substance. In the ventro-median fissure, the pia mater dips into this sulcus, covering each side of it. At the dorso-median sulcus, the inner layer sends in a long process which constitutes the *dorso-median septum*.

The external layer of the pia mater is bathed by the cerebrospinal fluid which separates the pia from the arachnoid. This surface of the pia mater is attached to the dura by means of the denticulate ligaments which extend from the lateral aspect of the spinal cord as a thin and delicate band of pia mater containing no blood vessels. The line of attachment is midway between the ventral and dorsal root fibers. By its inner border this ligament is attached without interruption to the spinal cord from its cephalic to its caudal extremity, and terminates at the beginning of the conus terminalis. Along its outer border, although it presents a firm attachment to the dura, the line of junction is not complete but is characterized by a series of denticulate processes between which are a series of arcades to permit the passage of root fibers. The first denticulate insertion is situated at the level of the lateral mass of the atlas; the last insertion occurs between the twelfth thoracic

and the first lumbar nerve. Each denticulate ligament has twenty-one points of lateral attachment, although in certain exceptional cases, this number may be reduced to sixteen or eighteen.

The cephalic extremity of the spinal pia mater is continuous with that covering the medulla oblongata. Caudally, it passes over the conus terminalis to cover the filum terminale which it envelops throughout its entire length.

Structure of the Membranous Envelopes of the Spinal Cord. The dura mater covering the spinal cord is continued into the skull, but in this relation presents a marked change from that observed in the vertebral canal. Immediately upon passing into the skull above the foramen magnum, the dura presents two distinct layers; (1) the parietal layer, firmly attached to the inner surface of the cranial bones, and (2), the visceral layer, in contact with the arachnoid. The spinal dura mater presents but a single layer, namely, the visceral or internal lamina which consists of a white fibrous tissue whose strands are longitudinal in direction and interlace with a small number of yellow elastic fibers. The dura contains arteries, veins and lymphatic vessels. It is innervated by meningeal branches from the dorsal roots of the spinal nerves.

The outer surface of the arachnoid is covered by endothelial cells, supported by a delicate framework of connective tissue fibers. The inner surface is reinforced by a certain number of yellow elastic fibers. The arachnoid contains no blood vessels, but nerve fibers from the trigeminus, as well as from the spinal nerves, have been described as forming a rich plexus ramifying throughout the membrane.

The pia matter is composed of two laminæ of connective tissue. The external lamina consists of fasciculi disposed longitudinally and parallel to the long axis of the spinal cord. According to some authorities, both surfaces of this lamina are covered by endothelial cells; this may be questionable concerning its inner surface, but the outer surface is undoubtedly endothelial in nature. The internal lamina, or *intima-pia*, so called by Key and Retzius, is formed by connective tissue fibers having a circular arrangement, in the meshes of which is a system of lacunæ filled with lymph. Prolongations from this lamina make their way inward accompanying the blood vessels, in all probability forming the perivascular lymph spaces. This lamina of the pia mater probably contains the lymphatic channels of the spinal cord.

In the strict sense there are no lymphatic structures found in the cord. Between the two laminæ which constitute the spinal pia mater, there is a small lymphatic space, the *intrapial lymph space*. This communicates with the subarachnoid space on the one hand and with the lacunæ of the *intima-pia* on the other, where these enter into the formation of the perivascular lymph spaces. The blood vessels of the pia are situated between the two layers which form this membrane, the internal lamina accompanying the vessels as they penetrate into the substance of the cord. This relation is of considerable clinical importance, as it explains the possibility of the subpial and intrapial hemorrhages. Lymphatics in the strict sense are not found in the pia mater. On the other hand, the rather spacious intrapial spaces

may, in the light of its connection with the perivascular lymph spaces, be regarded as a large lymph reservoir. A rich plexus of nerve fibers derived from the sympathetic system ramifies through the pia. These fibers are probably vasomotor in nature and serve to regulate the circulation in the spinal cord.

The Cerebrospinal Fluid. Filling the space between the pia and the arachnoid, is an important envelop completely surrounding the spinal cord. This is the *cerebrospinal fluid*. It is important not only because it serves as a buffer for the purpose of absorbing shocks which would otherwise fall too directly upon the spinal cord, and because it plays some nutritive rôle in the metabolism in the nerve tissue, but also for the reason that under many pathological conditions it is subject to marked departures from its normal characteristics.

The total amount of the cerebrospinal fluid contained within the ventricles of the brain and in the subarachnoid space varies from 100 to 150 cubic centimeters.

It is a colorless, transparent and odorless fluid. When held up to the light, it has the appearance of water and is free of flocculency under normal conditions. Its reaction is mildly alkaline: its specific gravity is 1.007. Within the subarachnoid space it exists under a definite tension which is slightly greater than atmospheric pressure. This pressure has been measured by means of lumbar puncture and is estimated to vary normally between 100 and 150 millimeters of water. When allowed to flow during lumbar puncture, it escapes drop by drop at about 60 drops per minute.

The constituents of the spinal fluid are :

Water	98.700
Cholesterin.	0.210
Sodium and potassium chloride	0.801
Sodium carbonate and calcium phosphate.	0.017
Sodium sulphate.	0.20
Globulin	0.088

The spinal fluid also contains glucose in amounts varying from 40 to 60 grams per liter and urea 0.25 to 0.35 grams per liter. It contains faint traces of peptone. There is no fibrinogen in the fluid, and if left to itself it does not coagulate under normal conditions.

In addition to these chemical substances, the spinal fluid contains a few cells which are exclusively lymphocytes when the fluid is normal. The number of these lymphocytes varies from 0 to 8 per cubic millimeter.

These constituents and properties of the spinal fluid are subject to marked variations under pathological conditions affecting the coverings of the spinal cord or the cord itself. The possibilities of these changes in the spinal fluid are too numerous to permit of extended mention here, but it may be said that no diagnosis of a disease affecting the nervous system is complete without an examination of the cerebrospinal fluid. This fluid is secreted in the ventricles of the brain and absorbed from the subarachnoid space.

Circulation of the Spinal Cord. The blood supply of the spinal cord depends upon two arterial plexus: (1) An extramedullary plexus, and (2) an intramedullary plexus.

The Extramedullary Plexus. This depends upon the concurrence of three sets of arteries: (1) The ventral spinal arteries, (2) the dorsal spinal arteries, and (3) the lateral spinal arteries.

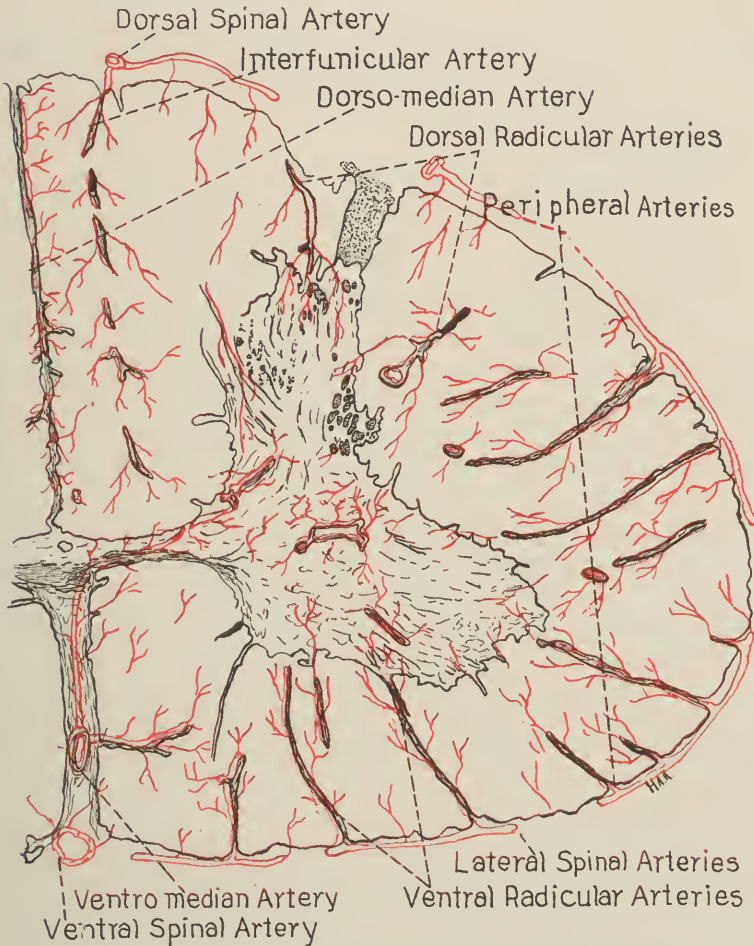


FIG. 114.—Diagram representing the spinal circulation.

The Ventral Spinal Arteries. There are two of these vessels, one upon the right, the other upon the left; they arise from the vertebral arteries a little caudal to the point where these vessels unite to form the basilar artery. From this point they descend into the vertebral canal, anastomosing in the midventral line to constitute a single trunk, the anterior spinal artery. This artery runs a long course down the ventro-median sulcus and usually terminates at the level of the fifth cervical segment. Below this point the anterior

spinal artery which descends in the ventro-median sulcus is formed by the confluence of the lateral spinal arteries.

The Dorsal Spinal Arteries. These arteries, also two in number, one upon the right and the other upon the left, arise from the vertebral artery a little caudal to the derivation of the anterior spinal arteries, and descend along the dorsal surface of the spinal cord, situated one upon either side of the dorso-median sulcus. Each dorsal spinal artery divides into two branches, one of which runs downward parallel to the dorso-median sulcus and mesial to the dorsal root fibers, while the other runs parallel but lateral to the root fibers. The dorsal spinal arteries extend as far as the fifth cervical segment of the cord. Below this level they are replaced by similar branches from the lateral spinal arteries.

The Lateral Spinal Arteries. These vessels are so called because they approach the cord from its lateral aspects. They take their origin from several different sources. In the neck they spring successively from the vertebral and ascending cervical arteries; in the thorax from the intercostal artery; in the lumbar region from the lumbar arteries; in the pelvis from the sacral artery. These vessels belong to the primitive segmental arterial system of the body, and manifest their segmental character by the fact that a pair of arteries passes through each pair of intervertebral foramina. In their passage they accompany the nerve roots. At the point where the nerve roots become divergent, each lateral spinal artery divides into two branches, one of which follows the anterior root fibers to the ventral surface of the cord, the other follows the dorsal root fibers to the dorsal aspect of the cord. The ventral branches of the lateral spinal arteries, upon reaching the midventral line, anastomose with each other across the median line and immediately give off an ascending and a descending branch from their point of union. The ascending branch anastomoses with the descending branch of the segment next above, and the descending branch anastomoses with the ascending branch from the segment next below. By the anastomosis of these ascending and descending branches, a ventral spinal artery is formed which extends from the level of the fifth cervical to the conus terminalis. The dorsal branches of the lateral spinal arteries extend inward until they reach the dorso-lateral sulcus, where they in turn divide into ascending and descending branches which anastomose in such a way as to form two dorsal spinal arteries, taking the place of the posterior spinal artery derived from the vertebral artery. An irregular anastomosis between all of these vessels gives rise to a rich plexus situated between the two layers of the pia mater.

THE INTRAMEDULLARY PLEXUS. These vessels are terminal arteries, that is to say, they do not anastomose. Three varieties of them are recognized, namely, the median arteries, the radicular arteries and the peripheral arteries.

The Median Arteries. The largest of the intramedullary vessels are the *ventro-median arteries*. These are the main branches of the ventral spinal artery, and at regular intervals, corresponding closely with the cord segments, they make their way into the ventro-median sulcus where they penetrate

the white commissure and finally reach the gray matter of the ventral gray column. At the point of penetration into the white commissure, the artery breaks up into a right and left branch, in this way supplying the vascular territory of the ventral gray column on either side.

The Dorso-Median Arteries. These arteries arise from the perineural plexus in the dorsal midline and extend inward through the dorso-median septum throughout its entire length. Their branches are distributed on either side to the column of Goll, but none of them enters the gray matter.

The Radicular Arteries. The *ventral radicular arteries*, two or three in number, arise from the perineural plexus in relation with the ventral roots, and dipping into the cord at this point, penetrate the white matter to reach the more ventral portion of the ventral gray columns.

The Dorsal Radicular Arteries. These arteries arising immediately from the dorsal spinal arteries in relation with the dorsal roots, penetrate the spinal cord at this point and enter the dorsal column of the gray matter. In this way the gray matter of the spinal cord is supplied by means of the ventral median, the ventral radicular and the dorsal radicular arteries. It also receives a few small branches from some of the peripheral arteries.

The Peripheral Arteries. The peripheral arteries arise from the perineural plexus and penetrate respectively the ventral, the lateral and the dorsal columns of the cord, so that three sets of vessels are recognized, *i.e.*, the *ventral peripheral*, the *lateral peripheral* and the *dorsal peripheral arteries*. With the exception of a few small branches from the lateral peripheral arteries, the vascular territory of these vessels is limited to the white matter. All of these intramedullary arteries have a more or less segmental relation to the cord. In the cervical region, where the columns of Goll and Burdach are most distinctly separated, a small vessel arises from the perineural plexus in relation to the dorsal column and penetrates the white matter along the dorsal paramedian septum. This is the *interfunicular artery*. The capillary plexus of the intramedullary arteries supplying the gray matter are extremely rich, while the capillary vessels in the white matter form a much less complicated plexus.

SPINAL VEINS. The intramedullary veins leave the different parts of the spinal column and become convergent upon six venous canals, three of which are situated ventrally, while three are in a dorsal position. Of the three ventral venous canals, there is one situated in the ventro-median sulcus, that is, the *ventro-median vein*. The other two are smaller and follow the line of emergence of the ventral roots. These are the *ventro-lateral veins*. The three dorsal canals have an analogous disposition. The *dorso-median vein* occupies the dorso-median sulcus and the two *dorso-lateral veins* are in relation with the dorsal root fibers. These veins anastomose freely and somewhat irregularly between the two layers of the pia mater. They follow the course of the dorsal and ventral nerve roots and drain into several extra-spinal veins. In the neck they are connected with the vertebral vein; in the thoracic region, with the intercostal veins; in the lumbar region, with the lumbar veins, and in the pelvis, with the lateral sacral veins.

LYMPHATICS OF THE SPINAL CORD. In the strict sense, there are no lymphatic channels in the spinal cord. The lymph is carried by means of interstices about the blood vessels which are known as the *Virchow-Robin adventitial lymph spaces*. Spaces of a similar character have also been described in connection with the nerve cells. These are known as the *pericellular lymph spaces*. There is some question, however, concerning their validity as lymphatic channels, although there can be little doubt that the perivascular lymph spaces serve the central axis in the capacity of actual lymph vessels. These channels are in connection with the large intrapial lymph space.

The Practical Significance of the Spinal Cord and Its Coverings. Enough has been said to indicate the clinical possibilities in the event of injury or disease, either in the coverings of the cord or in the cord itself. The more exact study of the symptoms arising from such disorders must be deferred until the functions of the cord have been studied in detail. It is sufficient to call attention to the fact that diseases of the bony envelope surrounding the spinal cord, such as tuberculosis, syphilis, or invasion by neoplasms, may quickly put the spinal cord in jeopardy and give symptoms, at first due to compression, and later to destruction. Such lesions would involve not only the spinal cord but the roots connected with it. Similarly, diseases of the membranous coverings of the cord may irritate, compress or destroy the nerve tissue. The inner vascular envelope about the spinal cord, the pia mater, is especially liable to inflammatory reaction, which is known as *leptomeningitis*. The dura mater also is subject to inflammatory change, a condition which is called *pachymeningitis*. Injuries or degenerative changes in an artery may lead to severe and extensive hemorrhages. These may be supradural, subarachnoid, subpial or intrapial in their position. The substance of the spinal cord is subject to many disintegrative changes which may destroy circumscribed areas or, in some instances, involve the greater portion of the entire organ. In the category of such changes may be listed the degenerations and scleroses, anemias, hyperemias and inflammations, the vascular accidents due to hemorrhage, thrombosis or embolism, tuberculosis, syphilis and tumors.

CHAPTER IX

THE SPINAL CORD

HISTOLOGY OF THE CORD SEGMENT

The Gray Columns of the Cord. Each spinal cord segment is composed of gray and white matter. The gray, or cell-containing substance, is situated near the center and surrounded upon all sides by the white matter. If it were possible to dissect the white matter away from the gray substance, the latter would appear as an irregular central core, the main body of which would be distributed in either half of the cord and connected across the midline by the *gray commissure*. The portion of the gray matter contained in each half of the cord presents the appearance of a long and somewhat peculiarly shaped rod. In this rod may be discerned a large *ventral gray column of cells* extending from the cephalic to the caudal extremity of the cord which, in its dimensions, is subject to considerable variation in different regions. In the more dorsal position may be distinguished another column of gray matter, the *dorsal gray column* of the cord, while in the thoracic region a third columnar portion of the gray substance occupies a lateral position and is called the *lateral gray column*. These three columns are not separated from each other, but represent specialized regions in the general arrangement of the gray substance. A transverse section of the spinal cord would pass through the gray columns and give rise to the characteristic appearance seen upon cross section of the cord. It is to be borne in mind that such a section gives the picture of a single plane only, while the gray matter as well as the white matter form continuous structures from one end of the cord to the other.

Transverse section of a thoracic segment shows that the gray matter is relatively less in size here than in other levels of the cord. It is possible to distinguish the narrow and somewhat elongated gray commissure connecting the gray matter in one half of the cord with that of the other. Near the center of this commissure is a small collection of cells marking the site of the formerly spacious central canal of the cord. This canal is usually obliterated in the adult; in many young subjects and occasionally in adult life, portions of the central canal may persist and be found patent here and there in the thoracic or cervical regions. At the lateral extremity of the commissure, the gray matter expands to form the body of the gray substance. The boundaries of this portion are ill-defined, although it deserves description because it serves as the junction of the ventral gray column with the dorsal gray column. In this area, especially well-marked in the thoracic region, there is a short projection of gray matter which constitutes the *lateral gray column*. The dorsal gray column extends as a large expansion into the dorsal portion of the spinal cord. In it may be distinguished a region continuous

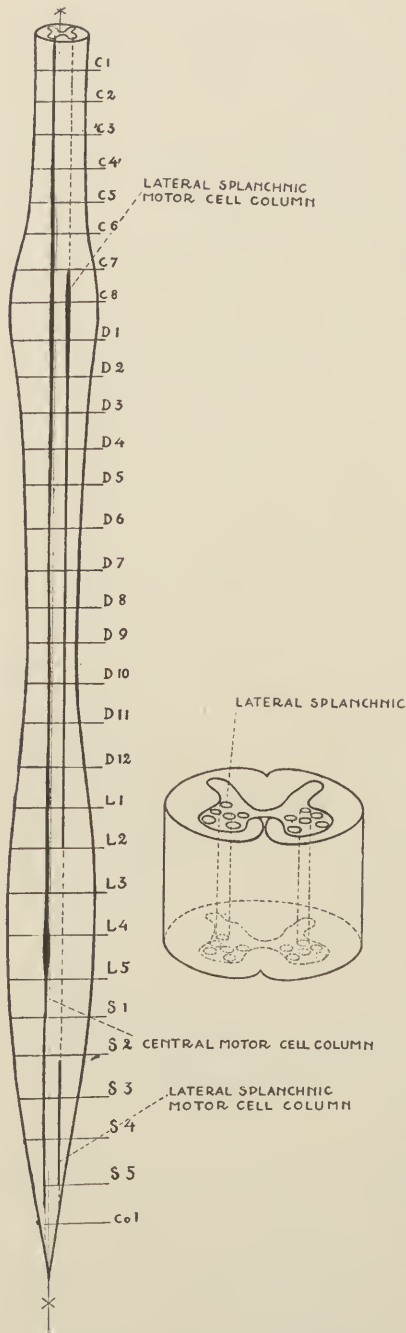


FIG. 115.—A diagrammatic representation of the vertical extent and relative transverse proportions of the lateral and central motor cell columns of the ventral gray matter of the spinal cord. The relative position of the lateral splanchnic cell column in transverse section is indicated at the right.

with the body of the gray substance. This is the *base*; a narrow, constricted zone contiguous with the base is the *cervix*; an expanded portion near the extremity of the column is the *caput*, investing which is a still more expansive region of the gray matter, the *substantia gelatinosa of Rolando*. A cross section of a typical thoracic segment of the spinal cord presents the following features:

1. The *ventral horn*, which is a section of the ventral gray column.
2. The *lateral horn*, which is a section of the lateral gray column.
3. The *body of the gray substance*.
4. The *dorsal horn*, which is a section of the dorsal gray column and presents the following parts;
 - (a) The base
 - (b) The neck or cervix
 - (c) The caput
 - (d) The substantia gelatinosa of Rolando.
 - (e) The zona spongiosa.
5. The *gray commissure*.

In the cervical region of the spinal cord there appears another element but little developed below the cervical enlargement. This is a reticular network of gray matter extending into the white substance from the base of the dorsal gray column and the body of the gray substance. It is the *formatio reticularis*.

Nerve-Cells in the Spinal Cord. The gray matter of the spinal cord contains several varieties of nerve-cells, all of them, however, multipolar in form with a single axone and usually a number of dendrites. These nerve-cells vary in size from the large elements, 135–150 micra in diameter, found in the ventral gray column, to relatively small elements, 10

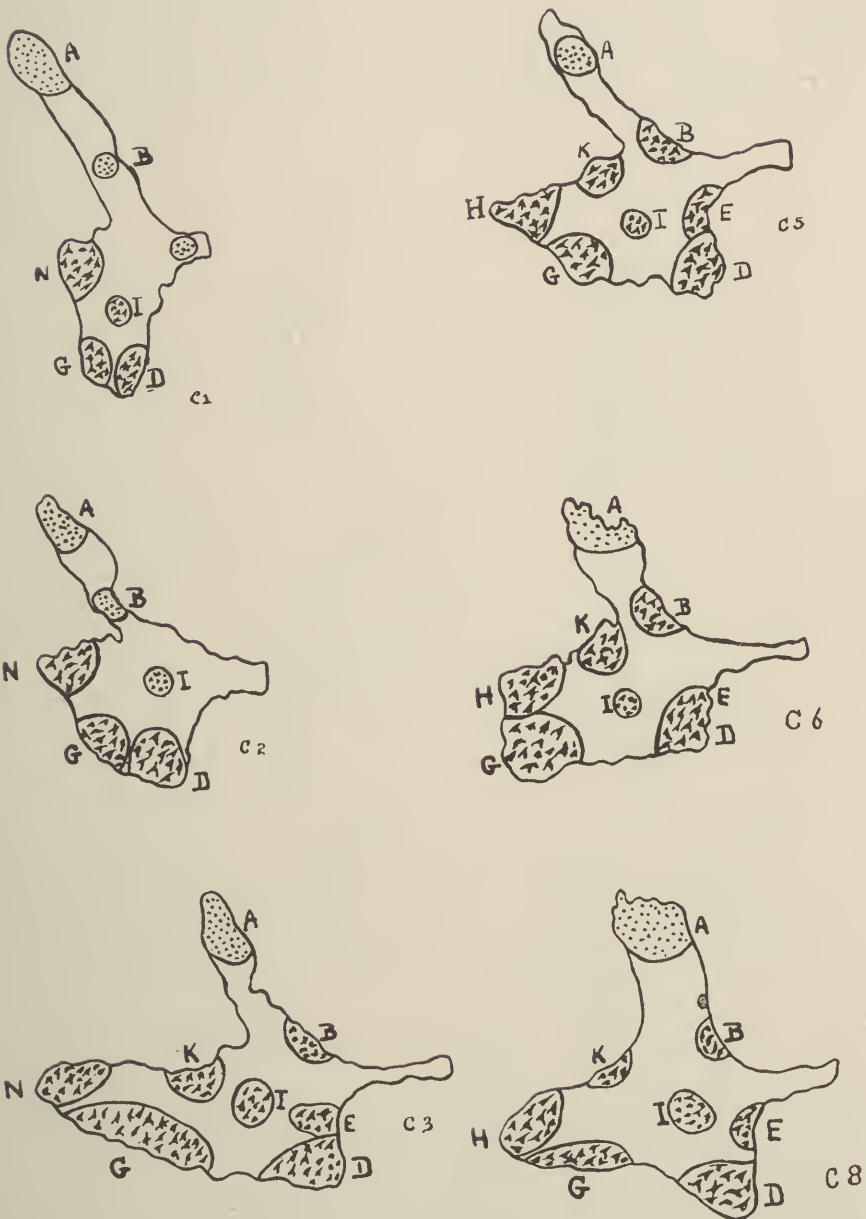


FIG. 116.—The cell groups in the gray matter of the cervical region of the spinal cord.

The letters on the diagrams represent the following cell-groups: *A*—The cells of the substantia gelatinosa of Rolando. *B*—The cervical and sacral nuclei of Stilling—the mesial basal group of the dorsal horn. *C*—Clarke's column. *D*—The ventro-mesial cell column. *E*—The dorso-mesial cell column. *G*—The ventro-lateral cell column. *H*—The intermediate dorso-lateral cell column. *I*—The central cell column. *K*—The dorso-lateral cell column. *L*—The lateral basal group of the dorsal column. *M*—The lateral cell column—splanchnic. *N*—The spinal nucleus of the spinal accessory nerve.

micra in diameter, observed in the substantia gelatinosa of Rolando. Both of Golgi's types of nerve-cells are observed, the Golgi type I being present in all portions, while the Golgi type II is restricted to the dorsal gray column. The Golgi type II cells send their axones ventrally from the dorsal gray column toward the ventral gray column, many of them entering and ending

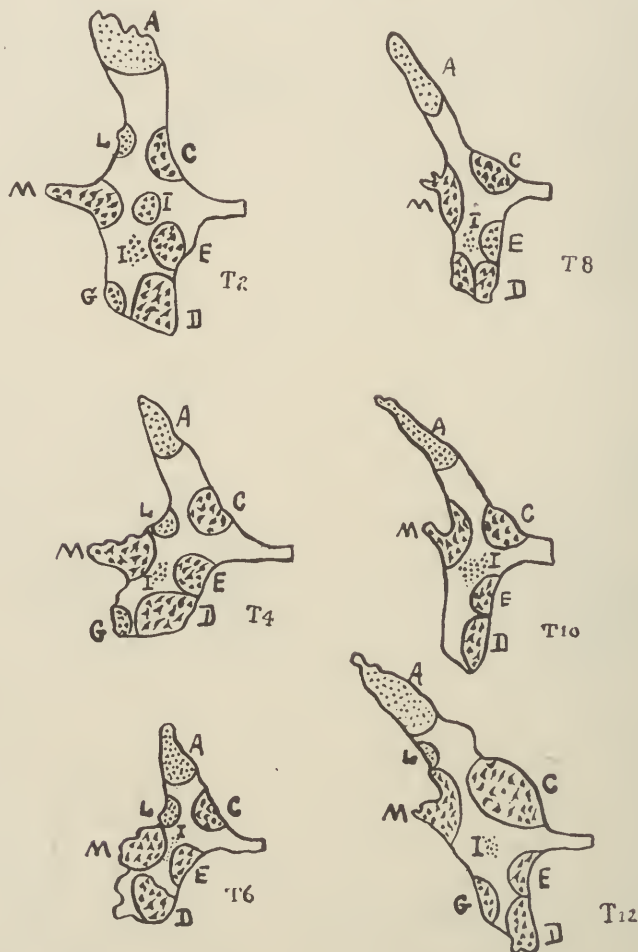


FIG. 117.—The cell groups in the gray matter of the thoracic region of the spinal cord. The letters on the diagrams represent the following cell-groups: A—The cells of the substantia gelatinosa of Rolando. B—The cervical and sacral nuclei of Stilling—the mesial basal group of the dorsal horn. C—Clarke's column. D—The ventro-mesial cell column. E—The dorso-mesial cell column. G—The ventro-lateral cell column. H—The intermediate dorso-lateral cell column. I—The central cell column. K—The dorso-lateral cell column. L—The lateral basal group of the dorsal column. M—The lateral cell column—splanchnic. N—The spinal nucleus of the spinal accessory nerve.

in this portion of the cord. Many of the axones from these cells cross to the opposite side through the gray commissure. There are two varieties of Golgi type I cells, *root cells* and *tract cells*.

ROOT CELLS. The ventral root cells, whose axones leave the gray matter, penetrate the white matter and escape from the spinal cord from the ventro-lateral sulcus as the ventral root fibers.

TRACT CELLS. Several varieties of tract cells are distinguished according to the course and relations of their axones.

1. *Tautomeric intrasegmental cells*, whose axones leave the gray matter to ascend or descend for a short distance within the segment in which they arise and end in the gray matter above or below the plane of their origin.



FIG. 118.—The cell groups in the gray matter of the lumbar region of the spinal cord.

The letters on the diagrams represent the following cell-groups: A—The cells of the substantia gelatinosa of Rolando. B—The cervical and sacral nuclei of Stillings—the mesial basal group of the dorsal horn. C—Clarke's column. D—The ventro-mesial cell column. E—The dorso-mesial cell column. G—The ventro-lateral cell column. H—The intermediate dorso-lateral cell column. I—The central cell column. K—The dorso-lateral cell column. L—The lateral basal group of the dorsal column. M—The lateral cell column—splanchnic. N—The spinal nucleus of the spinal accessory nerve.

2. *Heteromeric intrasegmental cells*, whose axones cross through the gray commissure to the opposite side and ascend or descend in the white matter for a short distance within the same segment to end in the gray matter above or below the plane of their origin.

3. *Tautomeric intersegmental cells*, whose axones leave the gray matter, ascend or descend in the white matter for several segments, and end in the gray matter upon the same side.

4. *Heteromeric intersegmental cells*, whose axones cross to the opposite side by means of the commissure, ascend or descend in the white matter for several segments, and end in the gray matter.

5. *Tautomeric suprasegmental cells*, whose axones arise in the gray matter and ascend to some suprasegmental destination in the brain upon the same side.

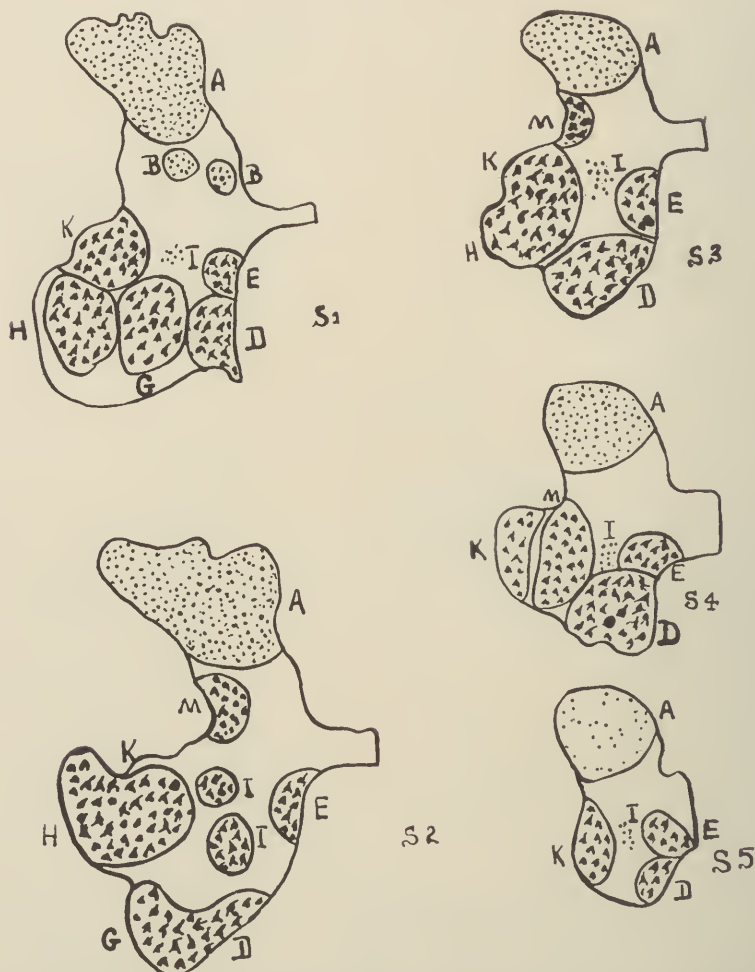


FIG. 119.—The cell groups in the gray matter of the sacral region of the spinal cord.

The letters on the diagrams represent the following cell-groups: A—The cells of the substantia gelatinosa of Rolando. B—The cervical and sacral nuclei of Stilling—the mesial basal group of the dorsal horn. C—Clarke's column. D—The ventro-mesial cell column. E—The dorso-mesial cell column. G—The ventro-lateral cell column. H—The intermediate dorso-lateral cell column. I—The central cell column. K—The dorso-lateral cell column. L—The lateral basal group of the dorsal column. M—The lateral cell column—splanchnic. N—The spinal nucleus of the spinal accessory nerve.

6. *Heteromeric suprasegmental cells*, whose axones leave the gray matter of one side, cross by way of the commissure, ascend in the white matter of the opposite side, to enter a suprasegmental structure of the brain on the side opposite to that in which they take origin.

ARRANGEMENT OF THE CELLS IN THE DIFFERENT PARTS OF THE GRAY MATTER

The cells in the ventral gray column of the cord are large, multipolar, stichochrome elements, varying in size from 135 to 150 micra in diameter. In the main, this portion of the gray matter is devoted to motor control and the arrangement of the nerve-cells found in it is of much physiological importance.

The Ventral Gray Column. This column may be subdivided into two secondary smaller columns of cells, namely, the *mesial somatic motor cell column* and the *lateral somatic motor cell column*.

THE MESIAL SOMATIC MOTOR CELL COLUMN. This column is almost continuous from the cephalic to the caudal extremity of the spinal cord. It has its significance in the fact that its cells supply the axial musculature of the body. It is divisible into a ventro-mesial and a dorso-mesial column.

The *ventro-mesial column* makes its appearance at the *first cervical segment*, increases rapidly in size until at the *eighth cervical* it causes a marked protrusion of the gray matter from this point to the lower limit of the *fifth sacral segment*. It is absent in the *first coccygeal*. Its cells supply the axial muscles upon the ventral surface of the body.

The *dorso-mesial column* makes its appearance in the *third cervical* and extends downward with but slight increase in its general diameters to the lower limit of the *fifth sacral segment*. It is absent in the *first coccygeal*. Its cells supply the axial muscles on the dorsal surface of the body.

THE LATERAL SOMATIC MOTOR CELL COLUMN. This column is divisible into three lesser columns. These columns are:

1. The *ventro-lateral column*, which begins at the *first cervical segment*, rapidly enlarges at the *fifth*, reaches its maximum dimensions at the *seventh* and disappears at the lower border of the *fourth thoracic segment*. Then occurs a long interruption in the column throughout the thoracic region. The ventro-lateral column makes its reappearance at the upper border of the *twelfth thoracic segment*, rapidly increases to the *fourth lumbar segment*, reaches its maximum at the *fifth lumbar segment* and disappears at the lower border of the *second sacral segment*.

2. The second lesser column is the *intermediate dorso-lateral column*. This also begins at the upper border of the *fourth cervical segment*, enlarges rapidly at the *fifth cervical segment*, reaches its maximum at the *seventh cervical segment* and disappears at the *eighth cervical segment*. It is interrupted throughout the entire length of the thoracic region, reappears at the *third lumbar segment*, reaches its maximum at the *fifth lumbar segment* and disappears at the lower border of the *third sacral segment*.

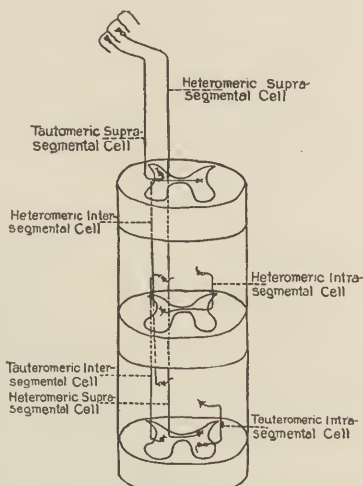


FIG. 120.—Diagram to illustrate the tract cells of the spinal cord.

3. The third subdivision of the lateral somatic motor cell column is the *dorso-lateral column*. This makes its first appearance at the *third cervical segment*, enlarges so that it produces a marked protrusion at the level of the *first thoracic segment* and disappears at the lower border of the *second thoracic segment*. It is absent throughout the rest of the thoracic region and does not reappear until the upper border of the *third lumbar segment* is reached. It rapidly enlarges in the *second sacral segment* and disappears at the lower border of the *fifth sacral segment*.

The lateral somatic motor cell columns occur only in the cervical and lumbo sacral enlargements; consequently they indicate nerve-cells whose function it is to supply the motor control to the extremities.

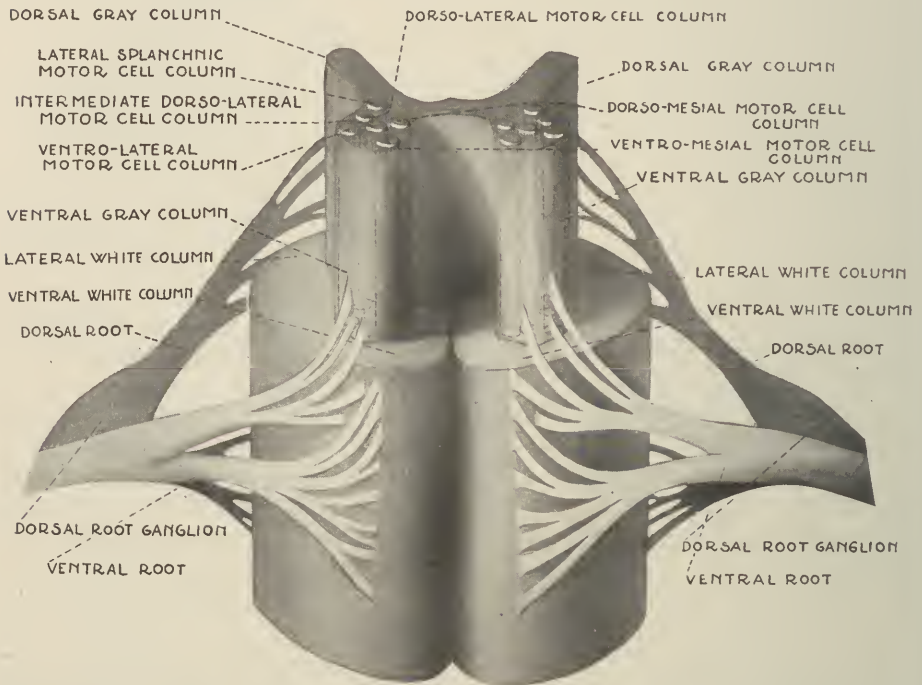


FIG. 121.—A diagrammatic representation of the spinal cord segment indicating the gray and white columns, the entrant or dorsal and the emergent or ventral root fibers, the dorsal root ganglion and the ventral gray column cell groups.

The ventral gray column also contains a group of cells centrally placed and constituting the *central column*. This makes its first appearance at the upper border of the *second lumbar segment*, reaches its largest diameters in the *fifth lumbar segment* and disappears at the lower border of the *first sacral segment*.

THE LATERAL SPANCHNIC MOTOR CELL COLUMN. Another long column of cells making a protrusion into the white matter is the lateral horn, which is found at the junction of the ventral gray column with the body of the gray substance. This is the *lateral splanchnic motor cell column*. The axones

from these cells make their way to the vegetative system. The cells are stichochrome in form, of medium size, varying from 12 to 60 micra in diameter. The lateral splanchnic motor cell column makes its first appearance at the upper border of the *first thoracic segment*, extends throughout the entire length of the thoracic segments, begins to diminish in the *first lumbar segment* and disappears at the lower border of the *second lumbar segment*. It makes its reappearance as a diffuse group of cells in the *second, third and fourth sacral segments*.

The Body of the Gray Substance. This structure contains a number of small groups of nerve-cells. These cells are most numerous in the enlargements, especially in the cervical region, and least numerous in the thoracic portion of the cord. In addition to these scattered groups, there is a more definitely circumscribed collection of cells situated in the body of the gray matter which is known as the *intermediate or middle nucleus*. This extends irregularly through the length of the cord; its cells are larger, stain better and show Nissl's bodies more

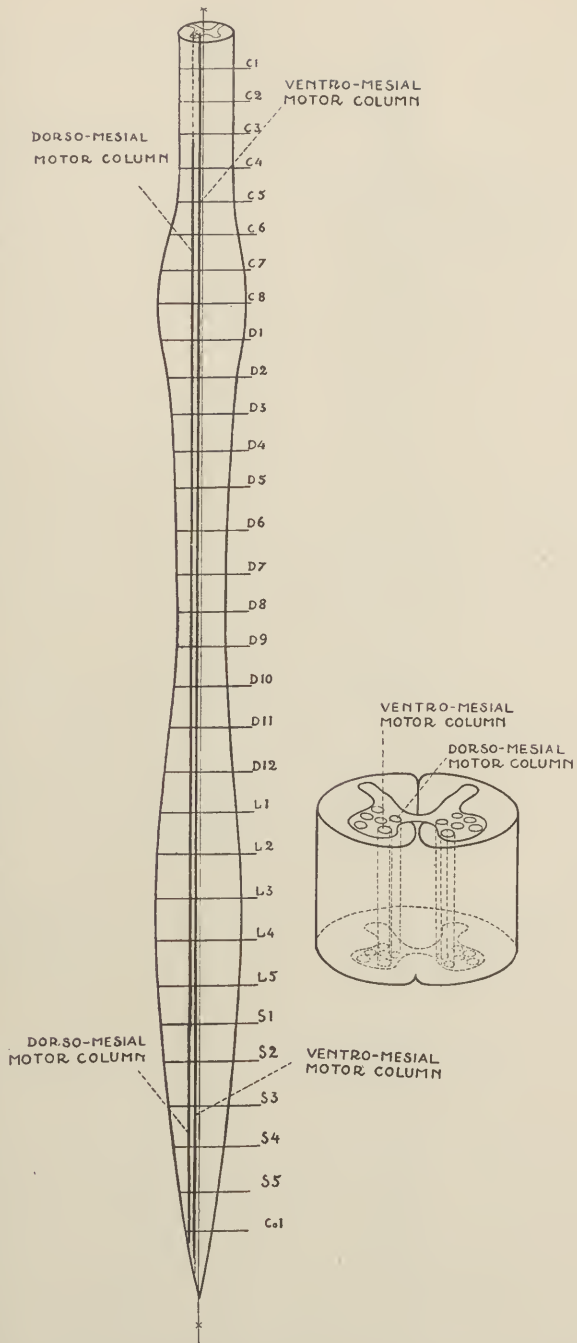


FIG. 122.—A diagrammatic representation of the vertical extent and relative transverse proportions of the mesial motor cell columns of the ventral gray matter of the spinal cord. The relative position of the cell columns in transverse section is indicated at the right.

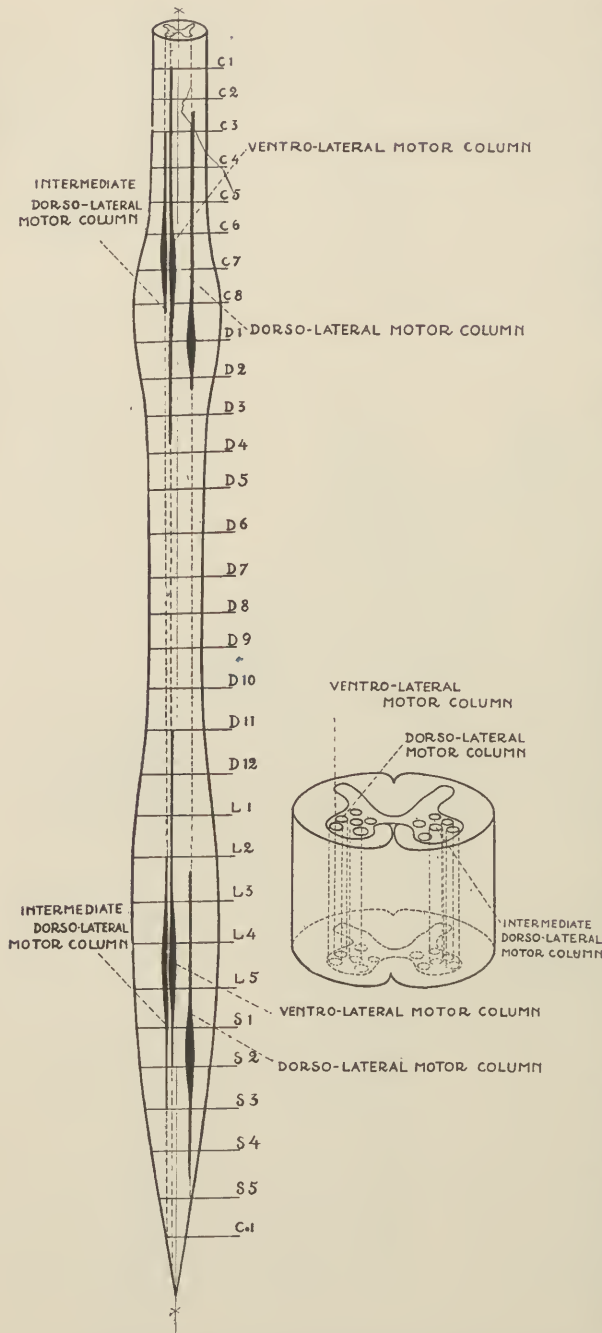


FIG. 123.—A diagrammatic representation of the vertical extent and relative transverse proportions of the lateral motor cell columns of the ventral gray matter of the spinal cord. The relative position of the cell columns in transverse section is indicated at the right.

clearly. A few of these cells send their axones to the opposite side by way of the ventral commissure, but most of them are directed to the lateral column of the same side, where they serve as ascending and descending intersegmental association fibers.

The Dorsal Gray Column. Several cell groups may be identified in the dorsal gray column.

THE BASE OF THE DORSAL GRAY COLUMN. In the base of this column, where it joins the body of the gray substance, there are two groups of cells, the *lateral basal group* and the *mesial basal group*.

The *lateral basal group* is most extensive in the cervical region and is comprised for the most part of cells of Golgi type II. The pyramidal axones seem to end about these cells, while their own axones go ventrally to the ventral horn. It is possible that the cells of this group serve as the short intercalated neurones which relay impulses received by way of the pyramidal tract to the root cells in the ventral gray column.

The *mesial basal group*, also known as the *posterior vesicular column of Clarke*, makes its first appearance in the *first lumbar segment*, and extends without interruption up to and through the *first thoracic segment*. It is best marked in the lower thoracic segments. A nucleus corresponding in position to that of Clarke's column is situated in the *third and fourth lumbar and first sacral segments*, and similarly a nucleus having the same topography appears in the *cervical segments*. These are known respectively as the *sacral and cervical nuclei of Stilling*. The cells, however, are different from those in Clarke's column, and a different physiological function is attributed to them. The cells of Clarke's column vary in size from 40 to 109 micra in diameter. They are multipolar elements whose axones extend outward to the lateral column of the same side. The nucleus as a whole and some of the cells in it are surrounded by a fine plexus of fibrils from the collaterals of the dorsal tract fibers and also from the lateral pyramidal tract. The cell bodies constituting Clarke's column have certain peculiarities which frequently lead to the belief that these cells are pathological. Normally, however, they present a picture which closely resembles that of central chromatolysis. Their nuclei are eccentrically placed, the cell bodies seem somewhat distended, Nissl's bodies are absent about the nuclei and appear only along the peripheral border of the cells. Quite frequently the cells of Clarke's column lodge a considerable amount of fat pigment. Another peculiarity of these cells is the fact that their dendrites are confined to this area of the column. Certain smaller cells have been observed in

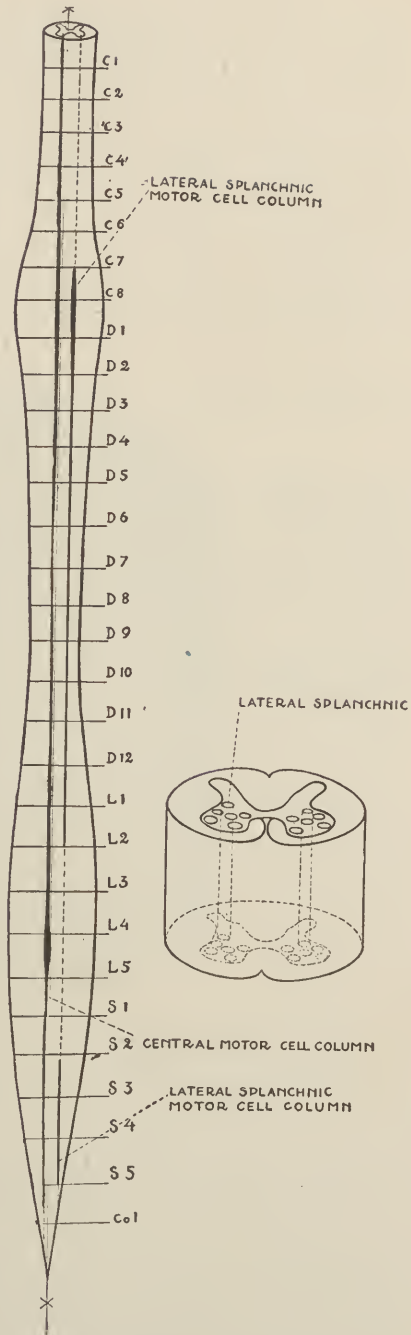


FIG. 124.—A diagrammatic representation of the vertical extent and relative transverse proportions of the lateral and central motor cell columns of the ventral gray matter of the spinal cord. The relative position of the lateral splanchnic cell column in transverse section is indicated at the right.

Clarke's column; these are situated around the periphery of the group and are known as the *limiting cells of Cajal* or the *tangential cells of Lenhossek*. These elements vary from 25 to 30 micra in diameter.

THE CERVIX OF THE DORSAL GRAY COLUMN. This region contains a small group of stellate and spindle-shaped cells. These are often referred to as the *solitary cells* of the dorsal horn, the axones of which extend to the ventral horn or to the gray commissure.

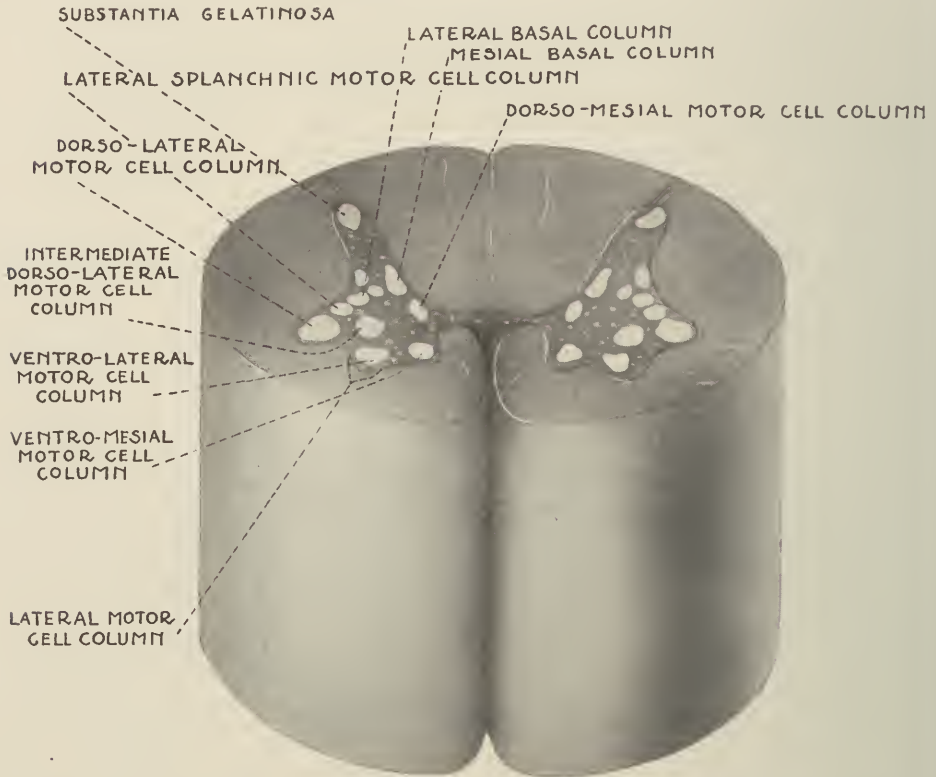


FIG. 125.—A diagrammatic representation of the spinal cord segment indicating the relative position and proportions of the gray and white matter and the approximate position of the most important cell groups in the gray columns.

THE CAPUT OF THE DORSAL GRAY COLUMN. There is a diffuse group of large stellate cells in this region whose dendrites pass into the substantia gelatinosa and whose axones pass to the dorsal and lateral columns.

THE SUBSTANTIA GELATINOSA OF ROLANDO. This contains many small scattered cells rich in dendrites. The axones of these cells pass to the lateral tracts along the margin of the substantia or to larger stellate cells whose axones have the same destination.

The Gray Commissure. The cells in the gray commissure are small and medium-sized commissural cells. Their axones extend in either direction toward the lateral tracts.

The *reticular formation* which, in the upper portion of the cervical region, appears to be continuous with the reticular formation of the medulla oblongata, contains large stellate cells with branching dendrites and axones which pass by way of the ventral and dorsal commissures into the lateral tracts.

THE WHITE MATTER OF THE SPINAL CORD

The white matter of the spinal cord is so arranged that it forms a sheath about the gray matter, except in some areas opposite the dorsal gray column where the gray matter approaches the circumference of the cord.

The emergence of the ventral root fibers and the entrance of the dorsal root fibers serve to divide the white matter into three columns which are of topographical as well as physiological significance.

The Dorsal White Column. The zone between the dorsal root fibers and the dorso-median septum is the *dorsal column*. It is made up of a number of conspicuous fasciculi. In the main, its function is sensory.

The Lateral White Column. The second zone lies between the dorsal root fibers and the ventral root fibers. It is the *lateral column*, which, although it contains a few fasciculi to serve the purposes of sensation, takes its physiological importance chiefly from the fact that most of the fasciculi in it furnish connections from the brain to the spinal cord.

The Ventral White Column. The third zone is limited by the ventro-median fissure and the ventral root fibers. It is the *ventral column*. Like the lateral column, it is largely motor in its function, serving to bring the spinal cord under the control of the higher centers.

The composition of the various fasciculi which enter into these three columns follows a well established law. According to this law the bundles of nerve fibers in the white matter lying closest to the gray matter are composed of axones which are relatively short or make a relatively short course, while the fasciculi farthest removed from the gray matter are made up of axones running a much longer course either from above downward or in the reverse direction.

DIFFERENCES IN THE CROSS SECTION APPEARANCES IN THE SEVERAL DIVISIONS OF THE SPINAL CORD

Cross sections illustrating the essential differences in the coccygeal, sacral, lumbar, thoracic and cervical segments of the cord are shown in the accompanying figures.

Cross Section through the First Cervical Segment. The circumference at this level of the spinal cord is oval. The average diameters are: transverse, 8.3 mm.; dorso-ventral, 6.3 mm.

The ventral gray column is relatively small and pyriform in shape. The lateral gray column is present but relatively small. The dorsal gray column has a large amount of substantia gelatinosa. The neck and body of the dorsal gray column are short and thick. The gray matter constituting the gray commissure is a large quadrilateral body, ventral to which is the white commissure. Between the lateral gray column and the dorsal gray column is the

reticular formation, a prominent element at this level. The ventral gray column and the dorsal gray column are about equal in size. The dorsal white column on either side is triangular in outline and more extensive than in the lower levels. The lateral white column occupies the largest portion of the white matter of the cervical region, while the ventral white columns are relatively small and separated by a deep ventro-median fissure.

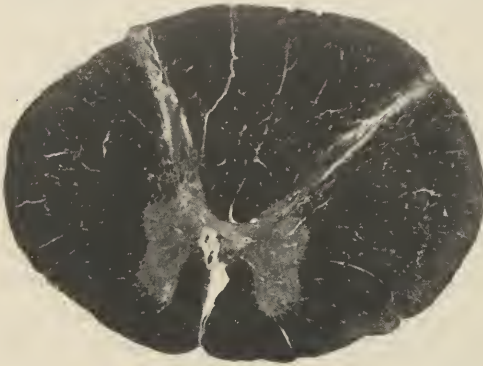


FIG. 126.—Cervical I.

The lateral gray column is prominent and projects laterally for a considerable distance. It contains an extensive group of large nerve cells. The combined size of the lateral and the ventral gray columns is approximately five times that of the dorsal gray column. The substantia gelatinosa is much reduced as compared with the upper cervical levels. The *area spongiosa* is removed from the periphery by a considerable distance. The neck and body of the dorsal gray column are short and thick. The central gray matter is present in the form of a thin strand of commissural gray matter. It is more attenuated at this level than in any other segment of the spinal cord. The ventral white commissure is correspondingly small. Situated between the lateral and dorsal gray columns is the formatio reticularis, which is much reduced in size as compared with that of the upper cervical levels.

The lateral white column is somewhat larger than the dorsal white column. The ventral white columns are separated by a deep and wide ventro-median fissure which, upon approaching the ventral white commissure, bifurcates, one branch going to the right and one to the left.

Cross Section through the Eighth Thoracic Segment. The circumference at this level is nearly circular, the dorso-ventral diameter being slightly less than the transverse. The average diameters are: transverse, 7 mm.; dorso-ventral, 6.2 mm.

Cross Section of the Eighth Cervical Segment. The circumference at this level is oval, the transverse diameter being nearly twice that of the dorso-ventral, representing the greatest transverse diameter at any level of the cord. The average diameters are: transverse, 12.5 mm.; dorso-ventral, 6.5 mm.

The ventral gray column is large and presents a mesial and a ventral projection, each containing specialized cell-groups.

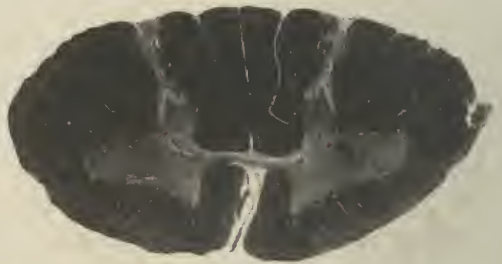


FIG. 127.—Cervical VIII.

The gray matter as a whole is smaller than in any of the other segments in the spinal cord. The ventral gray column is separated by a considerable distance from the periphery. There is a small lateral gray column. The dorsal gray column is narrow and tapering. It presents but a small amount of substantia gelatinosa which is removed from the periphery by a distance double that observed in the cervical region. The neck and body of the dorsal gray column are thick and longer than in the cervical region. The reticular formation between the ventral and lateral gray columns is feebly developed.

The dorsal, lateral and ventral white columns hold relatively the same proportions as in the lumbar levels.

Cross Section through the Second Lumbar Segment. The circumference at this level is oval, its transverse diameter being the longer. The average diameters are: transverse, 7.8 mm.; dorso-ventral, 5.7 mm.

The ventral gray column is relatively large and irregular in outline. The dorsal gray column shows a marked increase in the substantia gelatinosa of Rolando and presents a short neck and body. The entire gray matter gives the impression of having been compressed dorso-ventrally. The gray commissure is short and thick. Ventral to it is a massive white commissure.

There is no lateral gray column. The reticular formation is feebly developed.

The dorsal white column is larger than the lateral white column, while the ventral white column is relatively small. The ventro-median fissure abuts by its dorsal extremity against the white commissure. The dorso-median septum is separated from the ventro-median sulcus by the slight distance corresponding to

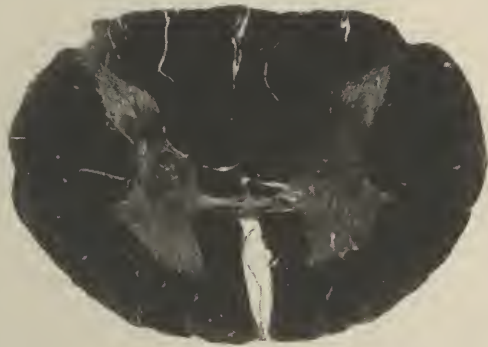


FIG. 129.—Lumbar II.

the width of the central gray matter and the ventral white commissure.

Cross Section through the First Sacral Segment. The circumference at this level is oval and shows the greatest prominence in the ventral quadrants. The average diameters are: transverse, 7.9 mm.; dorso-ventral, 5.8 mm.

The ventral gray column is large and is divided into a mesial and a lateral cell group. The dorsal gray column is likewise large and removed



FIG. 128.—Thoracic VIII.

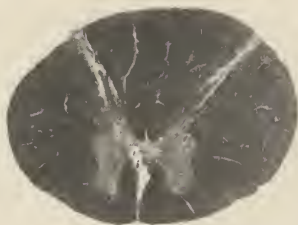


FIG. 130.—Cervical I.

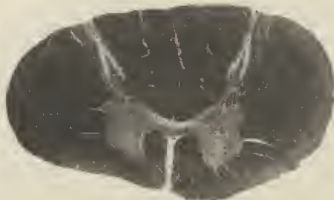


FIG. 131.—Cervical II.

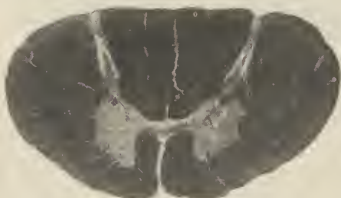


FIG. 132.—Cervical III.

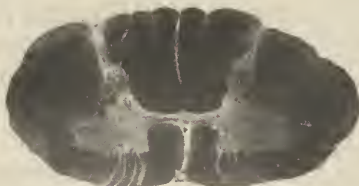


FIG. 133.—Cervical IV.

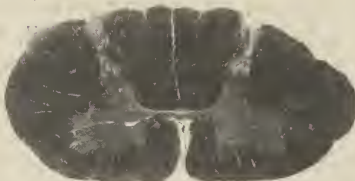


FIG. 134.—Cervical V.



FIG. 135.—Cervical VI.

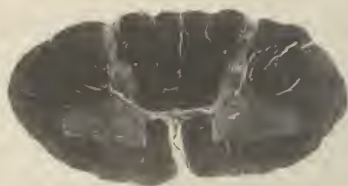


FIG. 136.—Cervical VII.



FIG. 137.—Cervical VIII.

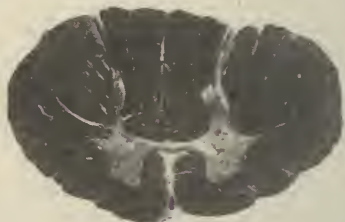


FIG. 138.—Thoracic I.



FIG. 139.—Thoracic II.

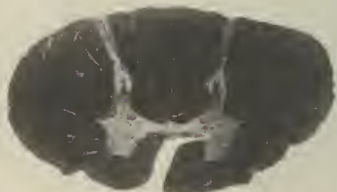


FIG. 140.—Thoracic III.



FIG. 141.—Thoracic IV.

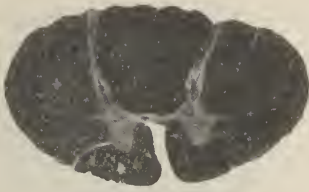


FIG. 142.—Thoracic V.

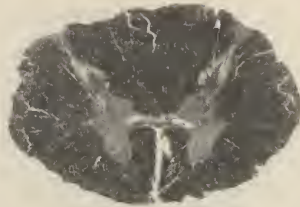


FIG. 148.—Thoracic XI.

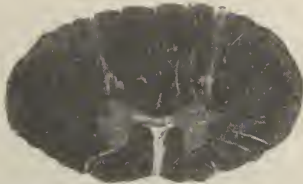


FIG. 143.—Thoracic VI.

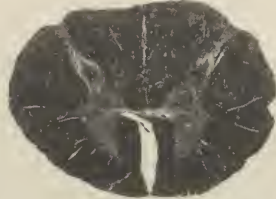


FIG. 149.—Thoracic XII.

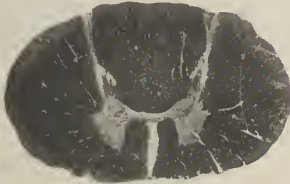


FIG. 144.—Thoracic VII.

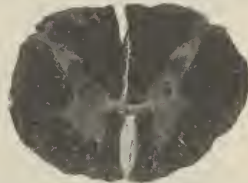


FIG. 150.—Lumbar I.

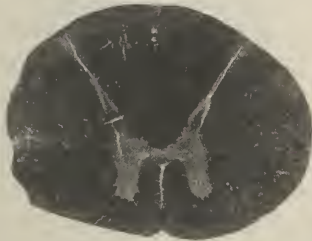


FIG. 145.—Thoracic VIII.

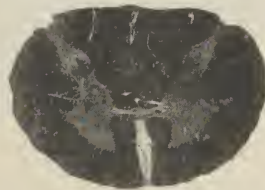


FIG. 151.—Lumbar II.



FIG. 146.—Thoracic IX.

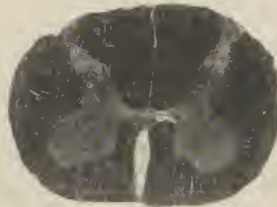


FIG. 152.—Lumbar III.



FIG. 147.—Thoracic X.

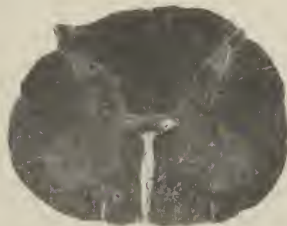


FIG. 153.—Lumbar IV.



FIG. 154.—Lumbar V.



FIG. 157.—Sacral III.

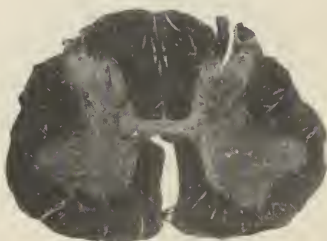


FIG. 155.—Sacral I.

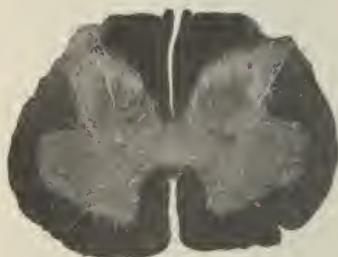


FIG. 158.—Sacral IV.

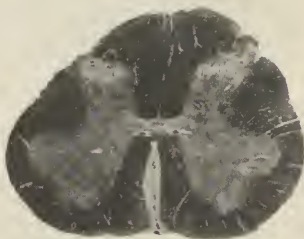


FIG. 156.—Sacral II.

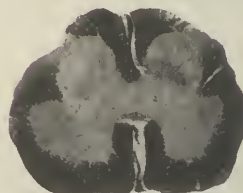


FIG. 159.—Sacral V.

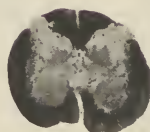


FIG. 160.—Coccygeal I.

but a small distance from the periphery. The substantia gelatinosa is larger here than in the lumbar segment. There is no appreciable neck or body in the dorsal gray column. The central gray matter constitutes a thick commissure, ventral to which is the white commissure. The reticular formation is feebly developed. The dorsal white column is still somewhat larger than the lateral white column, while the ventral columns are smaller than in the higher segments. All three columns of the white substance are relatively small. There is a considerable increase in the size of the gray matter.

The ventro-median sulcus is separated at its dorsal extremity from the ventral extremity of the dorso-median septum by the distance corresponding to the width of the central gray matter and the ventral white commissure.

Cross Section through the Fourth Sacral Segment. The circumference at this level is oval, the greatest diameter being transverse. The average diameters are: transverse, 5.3 mm.; dorso-ventral, 4.0 mm.

The ventral gray column is large, and its entire circumference is but little removed by the intervening white matter from the circumference of the segment. The dorsal gray column is also large, approaching the size of the ventral gray column. It presents neither body nor neck and passes with-

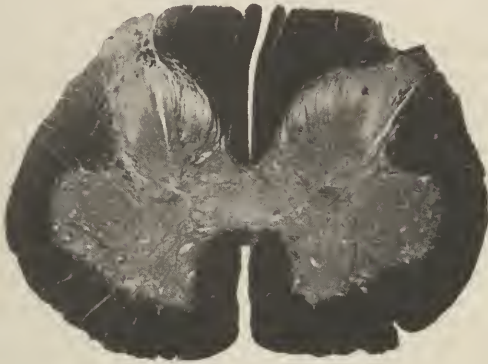


FIG. 161.—Sacral IV.

out line of demarcation into the ventral gray column. The central gray matter is large and lies about midway between the dorsal and ventral surfaces of the cord. Ventral to it is the large white commissure. The dorsal gray column is but little separated from the periphery of the segment. The reticular formation is feebly developed. The distance between the ventral and dorsal gray columns is slight because of the small amount of intervening white matter. Each of the three constituents of the white substance, the dorsal, lateral and ventral white columns, is relatively small.

Cross Section through the Coccygeal Segment. The circumference at this level is irregularly oval, its greatest diameter being dorso-ventral. The average diameters are: transverse, 2 mm.; dorso-ventral, 2.2 mm.

The ventral gray column is small, about one-half as large as the dorsal gray column. The central gray matter is also of small dimensions and the two bilateral masses of the gray matter are in close relation to each other. The reticular formation is feebly developed. A small ventral white commissure lies in front of the central gray matter. The dorsal ventral white columns are just beginning to appear. The largest constituent of the white matter at this level is the lateral white column which consists chiefly of the pyramidal tract.

The descriptions of the cross sections at these several levels represent the decisive changes from one division of the spinal cord to the next.

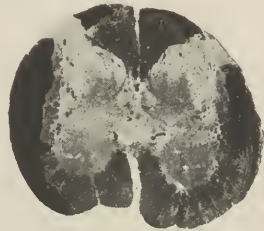


FIG. 162.—Coccygeal I.

CHAPTER X

THE SPINAL CORD

THE FUNCTION OF THE GRAY MATTER IN THE CORD SEGMENT

General Difference in Function of the Gray and White Substance. The function of the spinal cord segment depends upon its two constituents, the gray and the white matter. An understanding of the offices of these two substances in any given segment of the cord reveals the functional significance of the entire organ.

The gray matter is essentially a cell-containing substance. Its cells are concerned with the generation and dispatch of nerve impulses, and for this reason it is the *active* substance of the segment.

The white matter consists of nerve fibers whose function is the conduction of impulses arising in or dispatched to the cells in the gray matter. In this sense it is the *passive* substance. The cells in the gray matter are not all of the same type; they vary much both in size and structure, and this fact seems to justify the supposition that they do not all manifest the same functional activity.

FUNCTION OF THE VENTRAL SOMATIC MOTOR COLUMN

The cells in the ventral gray column are large, stichochrome elements, while the cells in the dorsal gray column are smaller and have a much less definite arrangement of their Nissl's bodies. Large stichochrome cells at once suggest motor function, and for this reason the ventral gray column is regarded as essential to the motor impulses which activate the executive organs of the body, the muscles. The dorsal gray column is, in the main, sensory in its type of function, and here many of the impulses coming from the various receptors are received and ultimately dispatched to their destinations in other parts of the central nervous system. The dorsal gray column, on the other hand, is not exclusively sensory in its activity, but serves the many purposes of intrasegmental and suprasegmental association. The body of the gray matter, as well as the gray commissure, also serves in this capacity of association. The larger cells in the ventral gray column send their axones to the skeletal muscles. Each of these cells holds under control a muscle fasciculus or group of such fasciculi. Every somatic impulse that the muscular tissue receives comes to it through the direct intervention of the ventral column cells.

Idiodynamic Control. The control which the ventral column cell exerts over the muscles is found upon analysis to be complex. In the first place, the health and normal activity of the skeletal muscles is dependent upon

these ventral column cells. Disease or destruction of them means impairment or disintegration of the muscles. The control of the muscles, in all their complex activity, is vested in the cells of the ventral gray column. These cells exercise a remarkable influence upon the life and maintenance of the muscle fiber as contractile tissue. When the muscle is deprived of this fundamental control, it ceases to live as muscular tissue and tends to revert to the simpler elements with which it is genetically related, the connective tissue. When the ventral column cell is injured as a result of disease or accident the muscle at once shows the effect of this alteration, not only in the loss of its contractile power, but by an actual diminution in its volume. Paralysis and atrophy, therefore, ensue when the motor nerve cell is thus affected. The atrophy or loss of volume is much more serious than a mere decrease in the size of the muscle fibers. It results in an actual solution of the contractile substance and the final replacement of it by fat and connective tissue. This process is spoken of as *muscular degeneration*, secondary

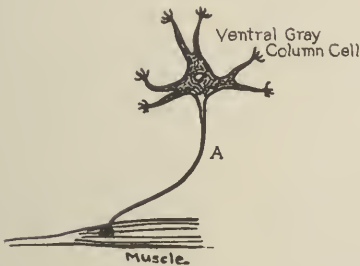


FIG. 163.—The final common pathway.
A—Idiodynamic control.

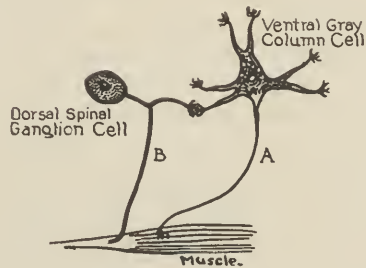


FIG. 164.—The final common pathway.
A—Idiodynamic control. B—Intrasegmental reflex and tonic control.

either to involvement of the ventral column cell or to an interruption in its axone connecting it with the muscle. This influence which the cell has over the muscle fiber appears to arise within the cell body itself and to be independent of all other sources of nerve impulses within the nervous system.

By means of the galvanic current it is possible to determine whether the muscular tissue is held in its normal control or to what degree this control is impaired. The normal muscle when stimulated by the cathode of the galvanic current shows upon closure (K.C.C.) a much more active contraction than when stimulated by the closure of the anode (A.C.C.). This reaction, indicated by the expression *K.C.C. greater than A.C.C.*, is the *normal galvanic contraction formula*. When the muscular tissue has been deprived of its control by the ventral column cell, this formula is reversed so that *A.C.C. becomes greater than K.C.C.*, which expression represents the *reaction of degeneration (R. D.)*.

The unsupplemented influence exerted by the motor nerve-cell directly upon the muscle is known as *idiodynamic control* of the ventral gray column.

Reflex and Tonic Control. The ventral column cell sends out many impulses to the muscles which differ materially from those essential to

idiodynamic control. Numerous connections are established between the ventral column cell and other parts of the nervous system. One of these connections brings about a relation with the dorsal root ganglion cell in such a way as to consummate a *neural arc*. This arc has its beginning in a receptor somewhere near the surface of the body, continues inward through the peripheral process of the dorsal root ganglion cell, reaches the spinal cord by way of the central process of this cell, and by means of a collateral from its axone, completes the connection with a cell in the ventral gray column, thus bringing the motor cell under the influence of impulses arising outside of the nervous system. Such impulses as are conveyed from the surface by means of the dorsal root ganglion contribute in an important manner to the activity of the motor cell. A constant flow of stimuli is transmitted to the muscle and serves to maintain the muscular tissue in a definite state of contraction, known as *myotonus*.

In consequence of this reflex connection, the muscle is subject to another variety of regulation called *reflex control*, which regulates reflex action. This phenomenon results from the stimulation of certain end-organs related to the muscle, particularly those organs which are located in the skin or in the tendon of the muscle. A good example of such reflex control is afforded by the biceps muscle which upon percussion of the biceps tendon contracts and thus produces a muscular response called a *reflex movement*.

The most classical of these movements is elicited by percussion over the patellar tendon, in response to which the quadriceps extensor muscle contracts forcibly and produces an extensor movement of the leg upon the thigh. This is the *patellar reflex*. It is dependent upon the stimulation of the receptors in the tendon spirals and the transmission of the stimulus by means of the dorsal root cells to the ventral gray column cells. These impulses stimulate the motor cells, and in consequence there develops in the muscle a rapid tonic contraction followed by immediate relaxation. By means of the connection with the afferent element of the dorsal root ganglion, the motor cell in the ventral gray column is enabled to exert *myotonic* and *reflex control* over the muscles. Should this cell become impaired or destroyed, myotonus as well as reflex activity ceases in the corresponding muscular tissue. This direct connection between the receptors and the motor cells in the ventral gray column constitutes the *simple reflex arc*: The motor responses determined by simple reflex arcs are represented by *simple reflexes* known as *reflex acts*.

Segmental Associated Control. The muscles of the body are made up of collections of muscle fibers, and the control of any one muscle is dependent upon the integrative or combined action of a number of nerve-cells. In order that these cells may cooperate adequately, it is necessary that a connection be established between them, so that an impulse arising in one cell may simultaneously stimulate all of the other cells normally associated with it. The motor cells of the ventral gray column are brought into such associative cooperation. When the cells controlling a given muscle lie wholly within a single segment, they must all be brought into action. This is known as

intrasegmental association. Each cell in the ventral gray column is capable of forming many such associations through its dendritic processes.

A motor act may require the contraction not alone of a single muscle, but of a group of closely related muscles whose contraction must be simultaneous in order that the act may be accomplished. Motor cells controlling all the muscles involved in such an act may occupy a number of neighboring segments of the spinal cord, so that it becomes necessary to associate all of them by a system of intercommunication. This type of muscular activity is made possible by means of *intersegmental association*. In this manner the motor cells in many segments of the cord may unite in the simultaneous dispatch of impulses to a group of muscles whose action gives rise to a definite performance.

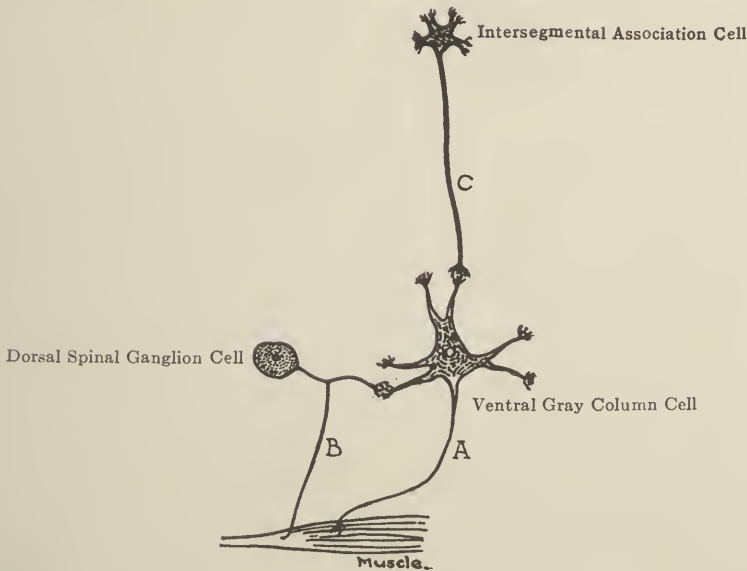


FIG. 165.—The final common pathway. A—Idiodynamic control. B—Intrasegmental reflex and tonic control. C—Intersegmental reflex control.

In many instances it is necessary for the segments to cooperate with each other, not merely as a longitudinal series upon the same side, but in such a way that the muscles upon one side of the body may perform acts simultaneous with those upon the opposite side. When such a combination is accomplished, it is by means of a *transegmental association*. This type of association may be confined to a single segment, or may bring several related segments into associated activity. The motor cell in the ventral gray column dispatches all of those impulses which it receives from other sources whose combination results in *segmental associated control*.

Vestibulo-Equilibratory Control. It is not alone from the spinal cord and the dorsal root ganglia that the motor cells receive the impulses which modify their activities. Impulses of much importance reach them from distant sources and from organs whose functions contribute to the regulation

of motor activity. Such are the impulses which come to the motor cell from the vestibule of the internal ear and particularly from the semicircular canals. These portions of the body are equipped with special receptors whose function it is to receive stimuli essential to static and dynamic equilibrium. The semicircular canals, according to the best interpretation

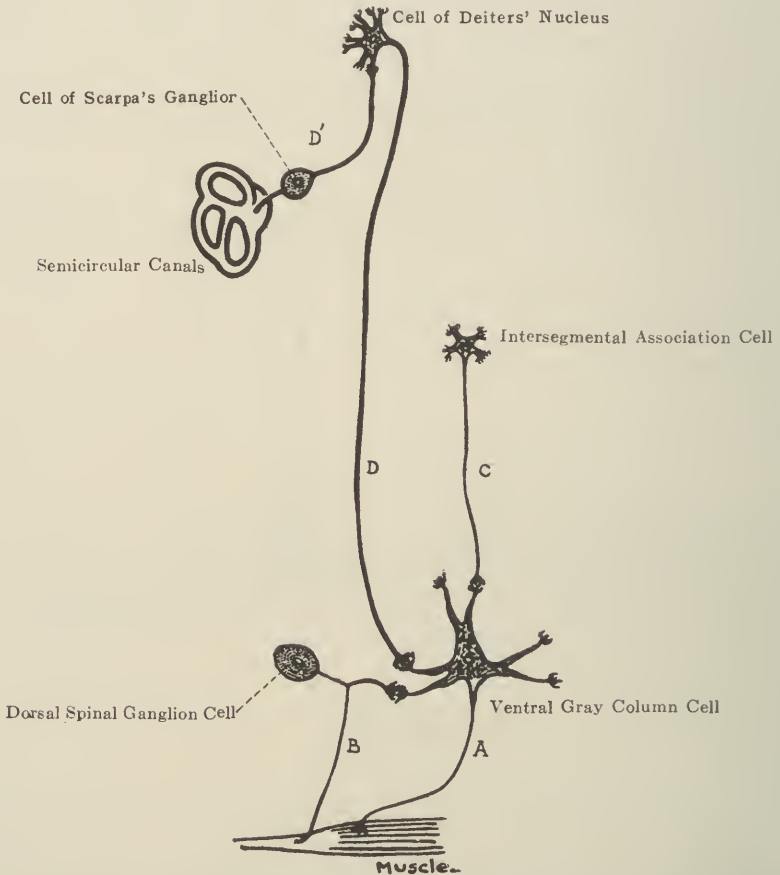


FIG. 166.—The final common pathway. *A*—Idiodynamic control. *B*—Intrasegmental reflex and tonic control. *C*—Intersegmental reflex control. *D*—Equilibratory control. *D'*—Primary vestibular neurone.

of their significance, play an important rôle in the maintenance of body equilibrium during locomotion, while the utricle and saccule seem to be designed for the purpose of body balance in standing or sitting. Either one or both of these mechanisms may be so disturbed as to make the balancing of the body difficult or impossible; in that event the patient shows a staggering in his gait or a swaying in his station, and, unless supported, may even lose his balance altogether. The stimuli received by the vestibular portion of the internal ear are transmitted to Deiters' nucleus in the medulla oblon-

gata, and from this relay station the impulses are dispatched to the motor cells to control the muscles in the interest of maintaining balance.

The motor cell may be deprived of the connection which normally furnishes these impulses to it. When such is the case, the patient manifests a marked disturbance in equilibratory control. It is probable that the cere-

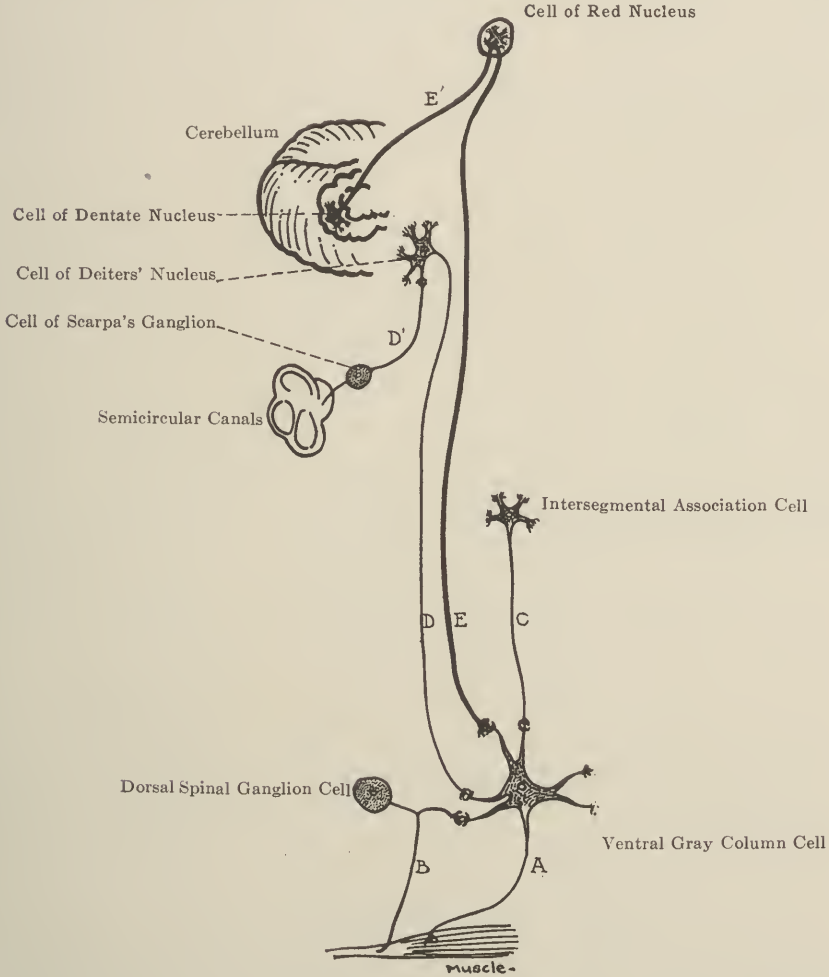


FIG. 167.—The final common pathway: *A*—Idiodynamic control. *B*—Intrasegmental reflex and tonic control. *C*—Intersegmental reflex control. *D*—Equilibratory control. *D'*—Primary vestibular neurone. *E*—Synergic control. *E'*—Dentatorubral neurone.

bellum enters into this function to a marked degree, but it is also clear that the connection between the semicircular canals, the utricle and saccule on the one hand, and the motor cells of the spinal cord on the other, may be accomplished directly without the intervention of any other organ. The significance of the vestibulo-equilibratory control will be discussed more in detail in a subsequent chapter.

Synergic Control. In all the performances of the skeletal muscles, in every act producing movement in a joint, a universal principle of coordination may be observed. The muscles of the body are so arranged that each individual muscle or each specialized group of muscles has its particular antagonistic group. In the arm, the triceps is the antagonist of the biceps during movements of flexion, and in the reverse order, during movements of extension, the biceps becomes the antagonist of the triceps. These apparent antagonists, however, are such in the morphological sense only, because they are by their positions opposed to each other. Physiologically, they act together and simultaneously. *During flexion of the forearm upon the arm, the biceps not only contracts sufficiently to produce the motion of flexion, but the triceps also contracts to determine the degree and the rate of this flexion.* In other words, the triceps acts as a check against the determinant motor force producing flexion. Similarly, when the arm is extended, the biceps becomes the check element against the action of the triceps. Biceps and triceps are, therefore, constantly working together and constitute a *synergic unit*. In this manner muscles of the body are arranged in groups of synergic units. If there is a disturbance in the synergism which normally exists in each synergic unit, the movements produced by such muscles become irregular and abnormal. The check element is not properly proportioned to the requirements of the determinant element, and a movement under these conditions becomes greater than its purpose requires. This makes necessary an over-correction on the part of the check element, which in turn is also in excess of the requirements of the movement. The motor act in consequence manifests a series of irregular oscillations; it loses the directness and precision which are characteristic under normal conditions. When such a disturbance exists, it is called *incoordination* or *ataxia*. The proper regulation of the synergic units of the body is the special function of the cerebellum. It is possible that other portions of the brain enter into this important type of motor control, but there can be no question that the cerebellum is fundamentally concerned in this activity. By means of a connection with the cerebellum, the motor cell in the ventral column is capable of distributing impulses whose purpose it is to establish and maintain *synergic control*.

Associated Automatic Control. The skeletal muscles receive impulses through the cells of the ventral gray column which enable them to perform actions much more complex than simple reflex movements. These actions are remarkable in the fact that they seem designed for the accomplishment of definite purposes. They appear to be so fundamental that they are not learned in the same manner that we learn to employ our voluntary movements. It seems to be the case that the species and not the individual has acquired this peculiar control over motion, and that the control itself is handed down ready for use without special effort on the part of the individual. It is perpetuated from progenitor to offspring and even transmitted in the course of evolution from the lower to the higher orders. A good example of these automatic associated actions is seen in the movements of

the arms during locomotion. In walking the arms swing backward and forward in definite relation to the movement of the legs. These arm movements are not merely the effect of gravitation upon the limbs, as may readily be seen when locomotion becomes energetic and forceful, as in a walking match.

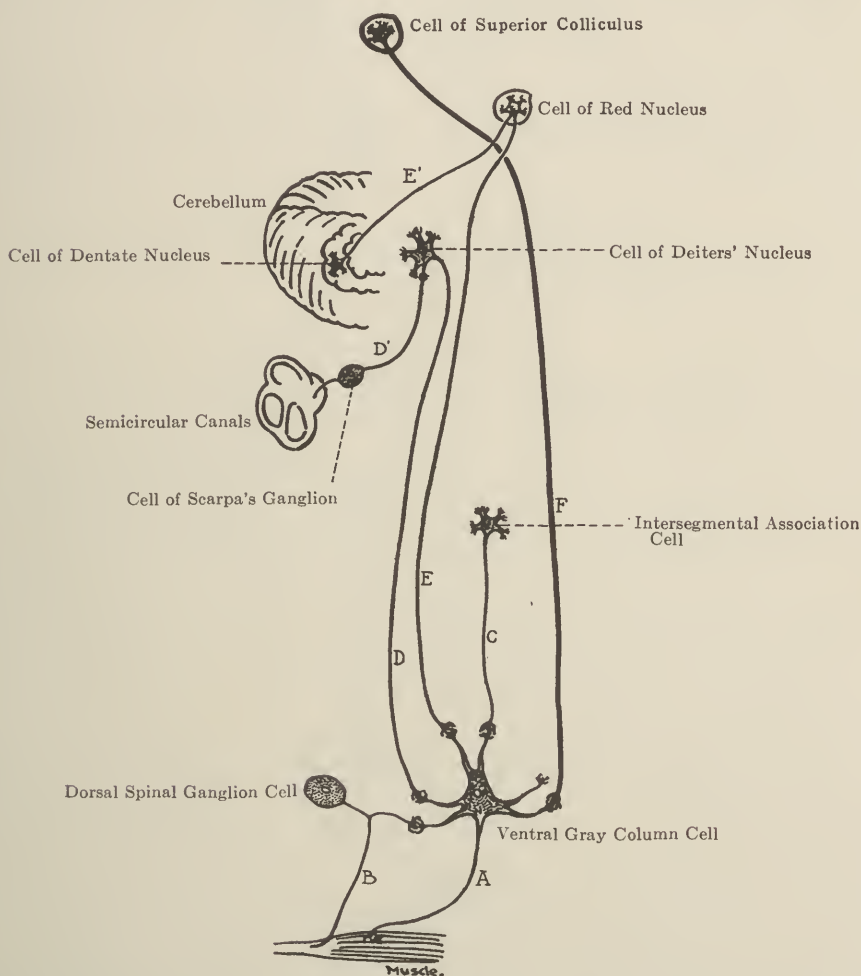


FIG. 168.—The final common pathway. *A*—Idiodynamic control. *B*—Intrasegmental reflex and tonic control. *C*—Intersegmental reflex control. *D*—Equilibratory control. *D'*—Primary vestibular neurone. *E*—Synergic control. *E'*—Dentato-rubral neurone. *F*—Oculo-cephalogyric control.

The swinging movements of the arms do not, at first glance, seem to have any definite purpose. They appear to be aimlessly associated with the movements of the legs. In considering the gait of the quadruped, the movements of the four extremities may be recognized at once as fundamental features of the locomotor mechanism. So essential is the synchronism in the movements of the fore and hind legs in animals which go upon all fours that the

persisting influence of this ancient, automatic association appears even in man. Even though the arms have been freed from actual participation as

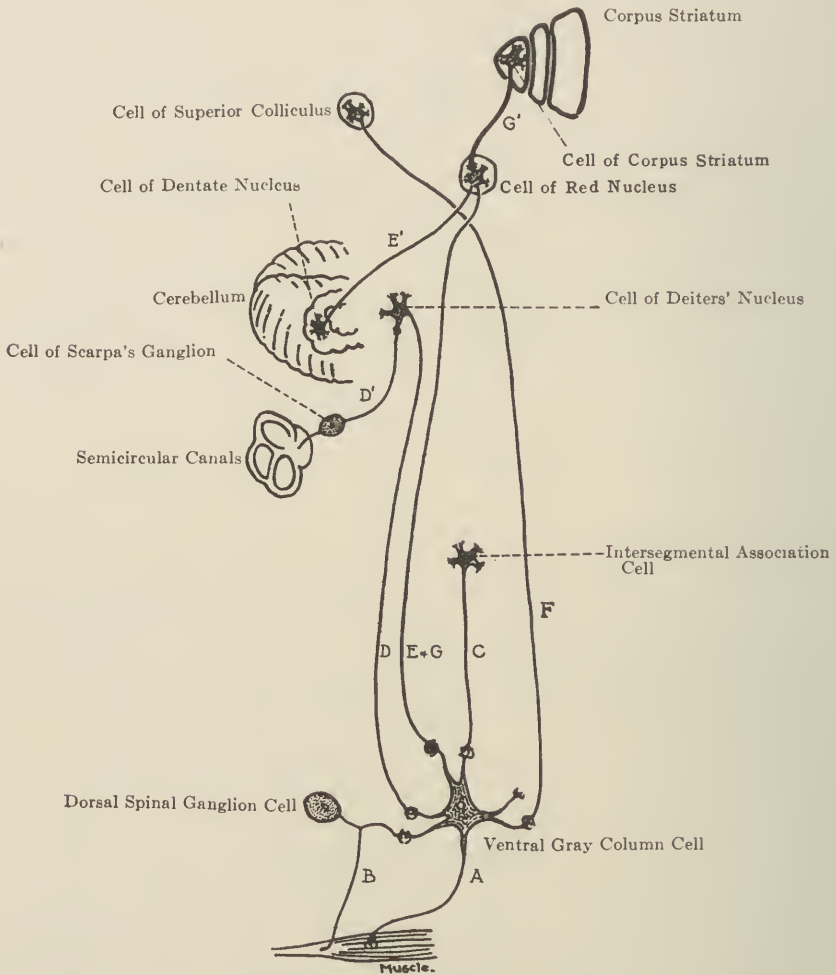


FIG. 169.—The final common pathway. *A*—Idiodynamic control. *B*—Intrasegmental reflex and tonic control. *C*—Intersegmental reflex control. *D*—Equilibratory control. *D'*—Primary vestibular neurone. *E*—Synergic control. *E'*—Dentato-rubral neurone. *F*—Oculo-cephalogyric control. *G*—Automatic associated control. *G'*—Striato-rubral neurone.

locomotor organs, they still remain under the control of the automatic association which characterizes the gait of the quadruped. A vast number of such automatic associated actions may be distinguished in man, the significance and character of which will be subsequently discussed. Suffice it to say that, as the result of recent clinical research, the function of automatic associated control has been ascribed to a certain part of the brain known as the *corpus striatum*. However much this supposition may be open to de-

bate, the fact remains that in certain diseases in which degeneration affects the corpus striatum, the most marked outstanding clinical feature is

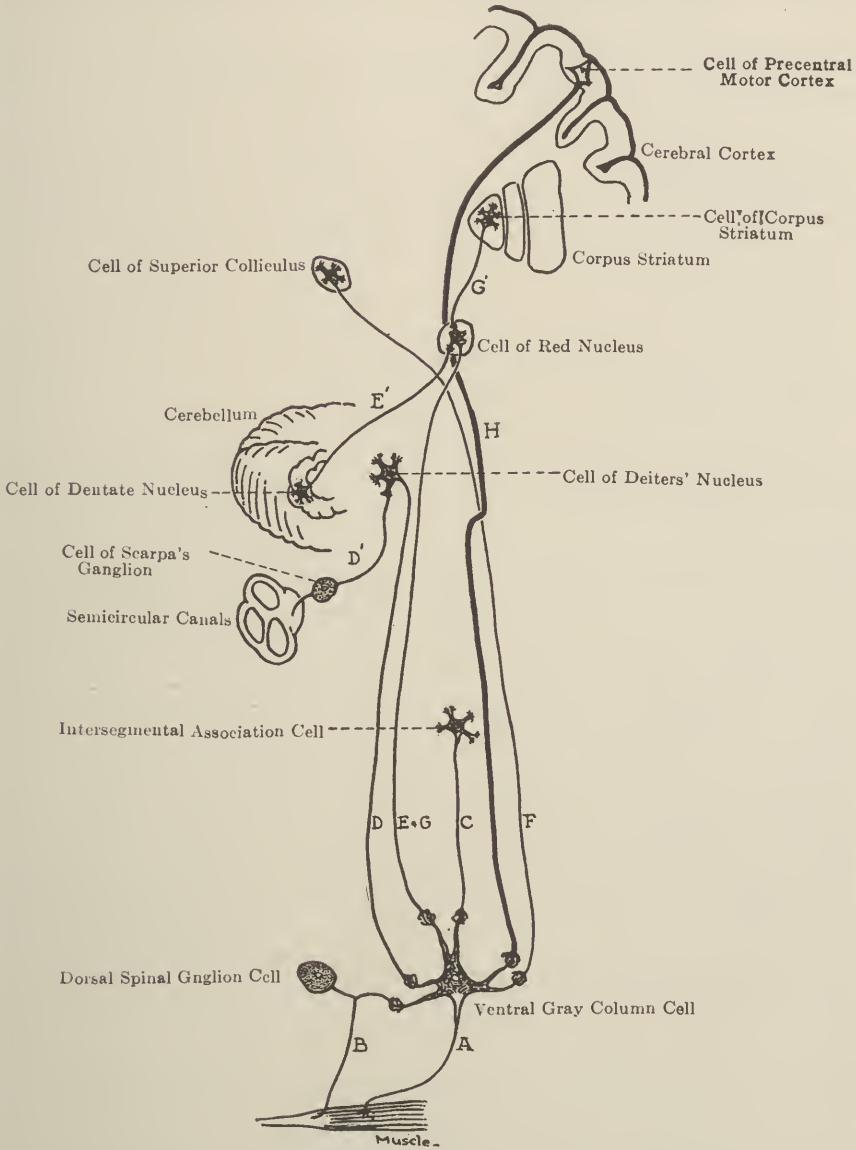


FIG. 170.—The final common pathway. *A*—Idiodynamic control. *B*—Intrasegmental reflex and tonic control. *C*—Intersegmental reflex control. *D*—Equilibratory control. *D'*—Primary vestibular neurone. *E*—Synergic control. *E'*—Dentato-rubral neurone. *F*—Oculo-cephalogyric control. *G*—Automatic associated control. *G'*—Striato-rubral neurone. *H*—Voluntary control; inhibitory control.

the more or less complete suppression of automatic associated actions. The many questions arising in connection with this type of motor control will be subsequently discussed in the chapter dealing with the corpus striatum.

In order that the impulses necessary for the automatic associated control may reach the muscle, the motor cell in the ventral gray column must establish a connection with the part of the brain in which this function is vested. It seems probable that impulses of a similar character, particularly associated with the visual function, may make their way to the motor cells and thus to the muscles. Such associated automatic acts based upon sudden extreme stimulation of the retina would be in the interest of protecting the eyes by associated movement of the arm and head. For example, in the presence of a blinding flash of light not merely are the eyelids tightly closed and the head flexed far forward, but the arm is automatically raised to shield the retina. A connection exists between the roof of the midbrain and the motor cells in the spinal cord and brain stem. This connection is known as the tecto-spinal tract. It undoubtedly affords the basis for the production of associated automatic acts of the eyelids, eyes, head and arm in a defensive mechanism to protect the retina and eye.

Voluntary or Volitional Control. The skeletal muscles are capable of producing long and sustained series of actions under the direction of the will. These actions are usually referred to as voluntary, because they are initiated and inhibited by volition. They differ from the automatic associated action in that they are acquired by means of individual experience. The muscular combinations and control necessary for their execution are not inherited, but are learned as the result of a slow and long process of repetition. A good example of such type of motor activity is afforded by handwriting, a skilled act which is acquired only after a tedious process of repeated efforts and persistent concentration of attention. The impulses of this volitional control arise in a certain area of the cerebral cortex known as the *Rolandic or motor area*. This portion of the brain contains many large pyramidal cells whose axones run a long course through the brain stem and spinal cord; these are the *pyramidal fibers* which eventually bring the impulses of volitional control to the motor cells of the ventral gray column. In addition to this regulation of the cerebral cortex there is a type of cortical control, as yet not altogether clearly understood, which exerts an inhibitory influence upon the motor cells of the spinal cord. This inhibitory influence makes itself apparent primarily in the tone of the muscles, for when the pyramidal cells of the motor cortex are delivering their impulses in a normal manner, the tone of the skeletal muscles is such as to adapt the muscular tissue most readily to the purposes of volitional action. Such a state of muscle tone may be called the *ideal muscle tonus*, because the muscle is neither too much contracted nor yet too much relaxed, but is in the tonic state, somewhere between these two extremes, best fitted to respond adequately to the dictates of the will. A muscular system which is too greatly contracted would of necessity respond slowly and in a rigid manner, while a muscular system too much relaxed would require an unnecessary amount of motor stimulation. This ideal muscle tonus is dependent upon the connection between the brain cells in the motor cortex and the motor cells in the spinal cord. When the connection between these two is interrupted or destroyed, the patient not

only loses the power of volitional control of the muscles in the parts affected, but the muscles themselves lose their ideal state of muscle tonus and manifest, in marked degree, a tendency to become unusually contracted. Excessive myotonus may be so extreme as to produce *malattitudes in the limbs*, drawing the forearm up into sharp flexion upon the arm, flexing the wrist upon the forearm and the fingers upon the hand. The leg may be affected in a similar manner. Such marked increase in tone, known as *hypertonicity* or *spasticity*, is accompanied by an increase in the reflexes of the affected parts. It would seem, therefore, that the influence of the motor cells in the cortex of the brain serves not only to maintain the ideal muscle tone, but also to prevent the reflexes from assuming more than their normal activity.

Other parts of the brain also exert an inhibitory influence upon the motor cells of the spinal cord, particularly the corpus striatum. In certain diseases affecting this region, the muscles become hypertonic and the body is held in a rigid, almost inflexible position. The corpus striatum, therefore, not only provides an automatic associated control but also applies to the motor cell of the spinal cord a certain degree of inhibition in the regulation of muscle tone. The cerebellum must not be overlooked in this connection. Its influence upon myotonus, however, seems to be different. When the cerebellar connection is injured or interrupted, the muscles, instead of becoming hypertonic, according to certain authorities show some diminution in tone. This condition is known as *hypotonus*.

It is probable that the reflex activities over which the motor cells in the spinal cord preside are influenced from at least four different sources:

First, from the dorsal root ganglion, by means of which the motor cell establishes its simple reflex connection with the muscle. When this connection is broken the reflex activity is abolished.

Second, from the motor cells of the cerebral cortex which normally inhibit the activities of the simple reflex arc and maintain the muscles in a state of ideal muscle tonus. When this connection becomes injured or interrupted, the reflexes are increased, as is also the muscle tonus, giving rise to a state of *hypertonus*.

Third, the motor cells in the corpus striatum so influence the motor cells in the spinal cord as to inhibit myotonus without affecting reflex activity. When this connection is injured or interrupted, the muscles become markedly hypertonic but the reflexes show little or no change.

Fourth, the influence of the cerebellum upon the motor cells of the spinal cord seems to be in the interest of maintaining the myotonus as well as the reflexes. Some authorities question this influence of the cerebellum.

Influences Affecting the Ventral Gray Column and their Possible Defects.

It will be seen that the motor cell in the ventral gray column receives impulses from many sources outside of itself. In addition to this it is possessed of an intrinsic activity upon which the integrity of the muscular tissue, as such, depends. The motor cell in the spinal cord in this light may be likened to a reservoir receiving supplies from many different areas but delivering them all to one common destination, the muscles. For this

reason the motor cell of the spinal cord has come to be known as the *final common pathway* of the motor system. By means of these cells every impulse necessary to the complex requirements of motor activity in the skeletal muscles is ultimately transmitted. *Idiodynamic control, reflex and tonic control, segmental control, vestibulo-equilibratory control, synergic control, automatic associated control and volitional control*, depend upon the motor cells in the spinal cord for their conduction to the muscles.

When the cell itself is destroyed, the muscle fiber supplied by it is deprived of its idiodynamic control, and passes into a state of degeneration. This condition is evidenced by a loss in the muscle volume and contour and also by the *reaction of degeneration*. This abnormal state of the muscle is known as *amyotrophia*, a condition in which the muscle is deprived of nutritional or trophic influences. An amyotrophic muscle fiber would show a complete paralysis, because no impulse coming from any source in the nervous system could reach it. Such a muscle fiber would also lose its reflex response and become atonic to the extent that the joints over which the muscle acted would become relaxed.

When the motor cell is deprived of the influences which come to it by means of the dorsal root ganglion cell, the muscle fiber loses its reflex response as well as its tone. It retains, however, its idiodynamic control and manifests no demonstrable decrease of volitional control, that is to say, it presents no paralysis.

When the motor cell is deprived of the impulses which come to it from the motor region of the cerebral cortex, the corresponding muscle fiber shows loss of volitional control; the reflex reactions become conspicuously more active and the muscle tone is markedly increased. It does not, however, show any evidence of a change in its idiodynamic control, and the muscle, under such a condition, usually manifests no variation in volume or contour.

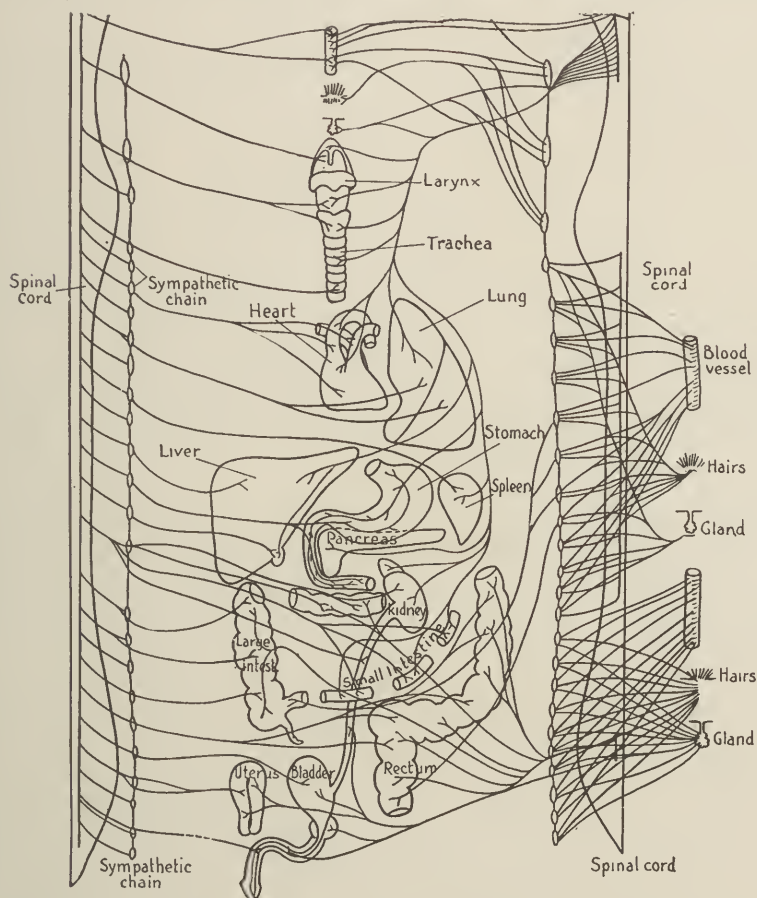
When the motor cell is deprived of the impulses which come to it from the cerebellum, the response of the muscle fiber shows a marked lack of synergic control, the reflex response may be diminished or lost, and the tone of the muscle may be reduced. Volitional and idiodynamic control, on the other hand, are retained as in the normal state.

FUNCTION OF THE LATERAL SPLANCHNIC MOTOR CELL COLUMN

This collection of cells entering into the formation of the gray matter of the spinal cord is found almost exclusively in the thoracic segments. It extends upward to the eighth cervical segment, and has a small representation in the first and second lumbar segments. The cells in this column send their axones out by way of the ventral roots and in small part by the dorsal roots. These axones immediately after passing the dorsal root ganglion become collected into a strand constituting the *white ramus* which establishes a connection with the ganglionated cord of the sympathetic system.

The cells in the sympathetic ganglia by means of their axis cylinder processes serve to distribute motor impulses to the smooth musculature

of the body and thus represent the splanchnic motor component of the nervous system. The type of motor control provided by the cells of this lateral splanchnic column differs conspicuously from that of the somatic motor column. Its chief distinction consists in the fact that there is no volitional regulation in this type of muscular activity. The exact connections between the lateral splanchnic cells and the motor cortex of the brain have



Afferent. FIG. 171.—The splanchnic components. *Efferent.*

Afferent.—This innervation provides the means by which the sensory stimuli reach the central nervous system.

Efferent.—This innervation provides the means by which the motor impulses are distributed to the involuntary musculature regulating the vital processes.

yet to be demonstrated. That these cells come under the influence of the cerebral hemispheres cannot be doubted from the evidence of clinical experience. The degree to which mental disturbances, such as anxiety and fear, may influence the cardiac action, the digestive movements of the stomach and intestines, and the reactions of the muscular coats of the blood vessels, is too well recognized to be disputed. By what part of the brain and by means

of what connecting fibers this cerebral influence is exerted, remains to be determined.

Differences in the Activities of Skeletal and Smooth Muscles. The control exercised by the lateral splanchnic motor column over the smooth musculature differs in another respect from that of the somatic motor control. In the smooth muscles the contractions tend to be constant; at least the major portion of this musculature in its distribution throughout the body presents an unceasing and persistent activity. There are no long, irregular intervals of rest such as is the case with the somatic muscles. The bulk of the splanchnic muscles, as for example in the heart and walls of the blood vessels, is continually in action. The type of this action is also a distinguishing feature; with few exceptions the character of the movement controlled by the lateral splanchnic motor cells is pulsatory and consists of a regular, uninterrupted series of rhythmical and alternating contractions and relaxations. This is true of the peristaltic movements of the gastro-intestinal tract, the pulsation of the heart and blood vessels, the respiratory contractions of the bronchial tree and the rhythmical contractions of the genito-urinary tract, including the ureter, the bladder and the uterus during the menstrual period and in labor. It is possible that this pulsatory character is imparted to the impulses arising in the lateral splanchnic motor cells by virtue of the connection with the ganglia of the ganglionated cord in the sympathetic system.

The splanchnic motor cells in the cord, like the somatic motor cells, are acted upon by afferent impulses. The stimulation of the mucosal surface of the stomach and intestines by the presence of food or foreign bodies, toxins or gases, will exaggerate the movements of these organs. The exact position of the fibers forming this afferent connection with the lateral splanchnic motor cells is not yet clear, nor are all the possibilities of chemical and other stimulation of these cells at present thoroughly appreciated.

A highly specialized group of the lateral splanchnic motor cell column, in the cervical region, contributes axones to the formation of the *spinal accessory nerve* which sends its fibers out to supply the trapezius and the sternocleido-mastoid muscles. Both of these muscles are skeletal in character, and this innervation would, therefore, tend to controvert the principle that the lateral splanchnic motor cell column supplies smooth muscles. This exception is of much importance. It will be seen later that these muscles are in part derived from the gill apparatus. The portions of these muscles having this derivation may be regarded as muscles which are fundamentally of the visceral type. In the process of adaptation they have become greatly modified and finally present the characters of skeletal muscles.

The column of cells situated in the position of the lateral horn, throughout its entire extent contains cells whose axones innervate the glandular tissue of the body. The control of the glands, like that of the smooth muscles, is accomplished through the intervention of the sympathetic system.

FUNCTION OF THE DORSAL ROOT GANGLION CELLS

The cells of the dorsal root ganglia are to be regarded as intrinsic portions of the gray matter of the spinal cord. In the early stages of development they are contained within the cord and subsequently migrate from it to assume their ventro-lateral position in the intervertebral foramina. In some lower forms, particularly in amphioxus, these cells never leave the spinal cord. This is a fact which gives further reason for regarding the dorsal root ganglion cells as integral portions of the gray matter. Although the cells vary somewhat in size and in the complexity of their axones, they are unipolar and present no dendritic processes. Their axone is T-shaped. It sends one process out peripherally and the other centrally to establish connection with the spinal cord. According to the arrangement of their Nissl's bodies, these cells are considered as *gryochromes*. Their function is sensory; they serve to receive and dispatch to the central nervous system all the sensory impulses which collectively enter into *somesthetic* or *body-feeling sensibility*. There are cells in each dorsal root ganglion designed to receive impulses from the viscera and thus contribute to the formation of *splanchnesthetic* or *visceral sensibility*. Some authorities believe that afferent fibers from the sympathetic system, which serve to conduct such impulses from the viscera to the dorsal root ganglia, arise from sympathetic ganglion cells. This idea appears improbable in view of the structural plan of the nervous system whose general character would seem to justify the belief that splanchnesthetic sensibility is provided with cellular elements in the dorsal root ganglia similar to those serving for somesthetic sensibility. The sensory cells of the dorsal root ganglia receive and transmit the several different qualities of sensibility as follows:

1. *Tactile sensibility (thigmesthesia)*.
2. *Muscle sensibility (myesthesia)*.
3. *Joint sensibility (arthresthesia)*. The muscle and joint sensibilities combine and thus give rise to *deep sensibility (bathesthesia)*.
4. *Vibratory sensibility (pallesthesia)*.
5. *Temperature sensibility (thermesthesia)*.
6. *Pressure sensibility (piezesthesia)*.
7. *Pain sensibility (algesthesia)*.

FUNCTION OF THE TRACT CELLS IN THE SPINAL SEGMENT

Scattered tract cells in the dorsal gray column of each spinal segment serve to transmit to the brain the impressions which have to do with temperature sensibility. Other cells transmit to the cerebellum impulses received from the muscles in the interest of synergic control.

The tract cells in the *mesial basal nucleus* of the dorsal gray column (the column of Clarke) are concerned in transmitting impulses from the muscles to the cerebellum for the purposes of synergic control.

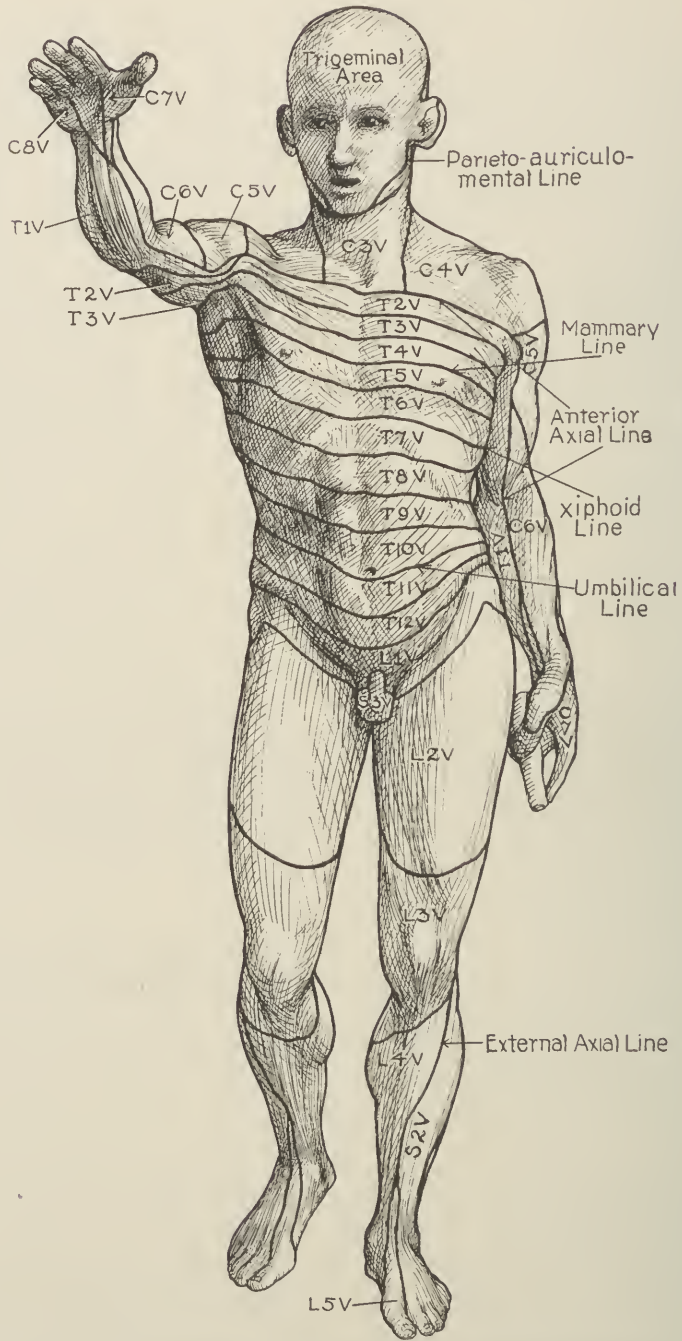


FIG. 172.—The somatic dermatomes; ventral view. (*Déjerine.*)

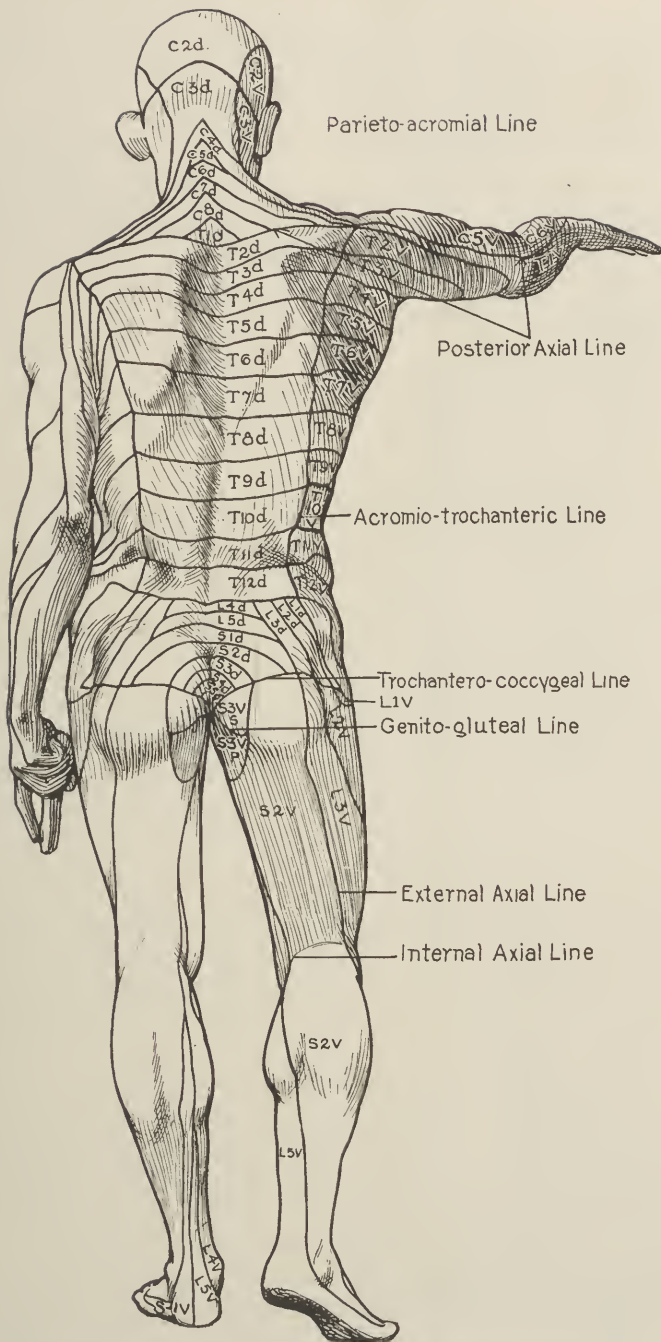


FIG. 173.—The somatic dermatomes; dorsal view. (*Déjerine.*)

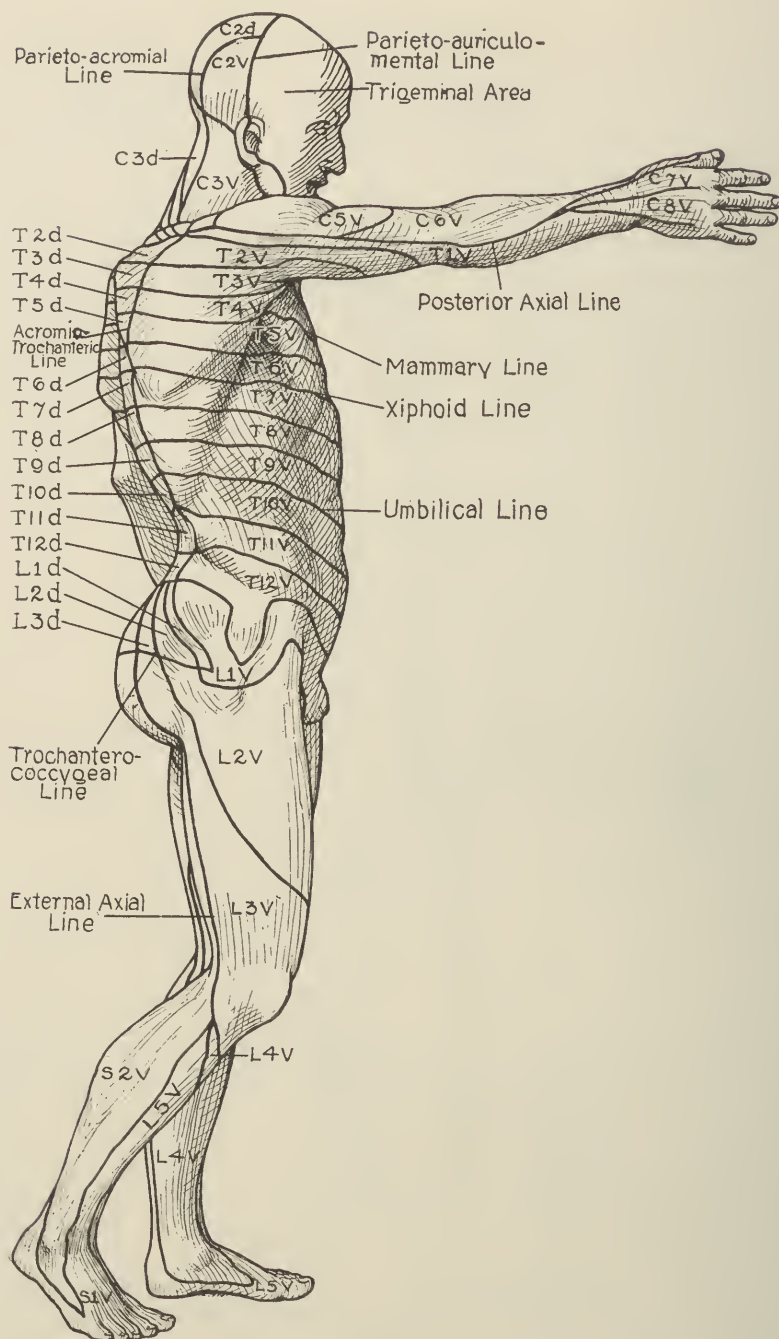


FIG. 174.—The somatic dermatomes; lateral view. (*Déjerine.*)

The tract cells in the caput of the dorsal gray column receive impulses from the dorsal root ganglion cells and transmit them to the brain in the interest of thermic sensibility. The cells in the cervix of the dorsal gray column in all probability participate in this type of conduction.

The tract cells in the substantia gelatinosa of Rolando serve to transmit the impulses which are concerned in algesthetic or pain sensibility.

In all portions of the gray matter of the spinal cord there are many tract cells which serve as intra- and intersegmental association connectors.

SUMMARY OF THE FUNCTIONS OF THE GRAY MATTER OF THE SEGMENT

1. The ventral gray column represents the final common pathway for all motor impulses concerned in the activity of the somatic motor system.

2. The lateral splanchnic cell column represents the final common pathway for all impulses concerned in the activity of the splanchnic motor system.

3. The dorsal root ganglia serve for the transmission into the spinal cord and thence to the brain of all qualities of somesthetic and splanchnic sensibilities. They also establish segmental reflex arcs.

4. The body of the gray matter contains cells chiefly concerned in the conduction of those afferent impulses from the muscles necessary to the purposes of synergic control.

5. The mesial basal nucleus (column of Clarke), situated at the base of the dorsal gray column, is exclusively concerned in transmitting to the cerebellum the impulses from the muscles necessary to synergic control.

6. The head of the dorsal gray column transmits to the brain impulses concerned in the thermic sensibility.

7. The cells of the substantia gelatinosa of Rolando transmit to the brain those impulses which have to do with pain sensibility.

THE CUTANEOUS SENSORY, MUSCULAR AND REFLEX ZONE OF THE BODY

A tabulation of the cutaneous sensory, muscular and reflex zones of the body controlled by the several segments of the spinal cord is given here in detail to facilitate the localization of lesions affecting this part of the nervous system.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
2nd Cervical Ventral	Mastoid, auricular, transverse branches of superficial cervical plexus.	Retro-auricular area of scalp as far dorsal as parieto-acromial line, superior external portion of auricle of ear, small area over mandible.	2nd Cervical
2nd Cervical Dorsal	Great occipital nerve (posterior branch of 2nd cervical).	Scalp from vertex to inferior curved line, between two parieto-acromial lines.	

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
3rd Cervical Ventral	Superior transverse cervical nerve, suprasternal and supraclavicular nerves of cervical plexus.	Ventral surface of neck from nuchal fold to anterior axial line as it crosses thorax.	3rd Cervical
3rd Cervical Dorsal	Posterior branch of 3rd cervical nerve.	Dorsal surface of neck from inferior curved line to 3rd cervical spinous process.	
4th Cervical Ventral	Supraclavicular and supra-acromial branches of superficial cervical plexus.	Covers shoulder as far out as junction of upper and middle third of deltoid muscle.	4th Cervical
4th Cervical Dorsal	Posterior branch of 4th cervical nerve.	Small area between the parieto-acromial line and interscapular triangle.	

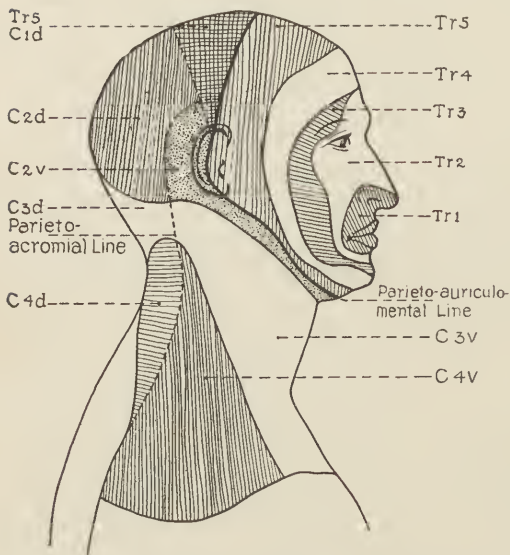


FIG. 175.—Facio-cranio-cervical dermatomes.

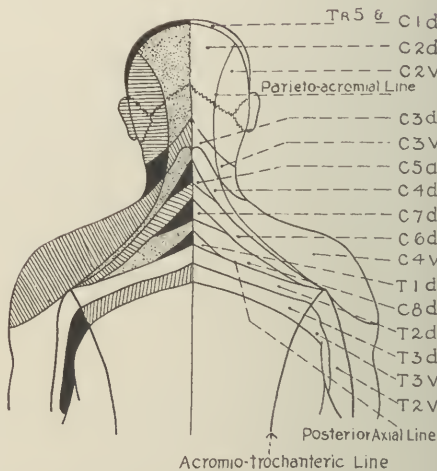


FIG. 176.—Interscapular triangle.

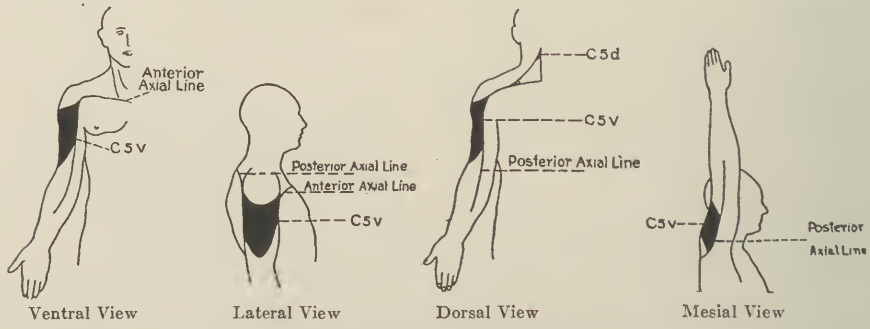


FIG. 177.—Fifth cervical dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
5th Cervical Ventral	Anterior branch of the circumflex, also its lateral brachial cutaneous branch.	Middle third of arm, radial side from anterior to posterior axial lines.	5th Cervical
5th Cervical Dorsal	Posterior branch of 5th cervical nerve.	Apex of interscapular triangle.	
6th Cervical Ventral	External and internal branches of radial nerve. Anterior and posterior terminal branches of musculocutaneous nerve. Anterior terminal branch of radial nerve.	Lower third of arm from anterior to posterior axial line on radial side, also forearm on same side and hand as far as first phalanx of thumb.	6th Cervical
6th Cervical Dorsal	Posterior branch of 6th cervical nerve.	Interscapular triangle.	

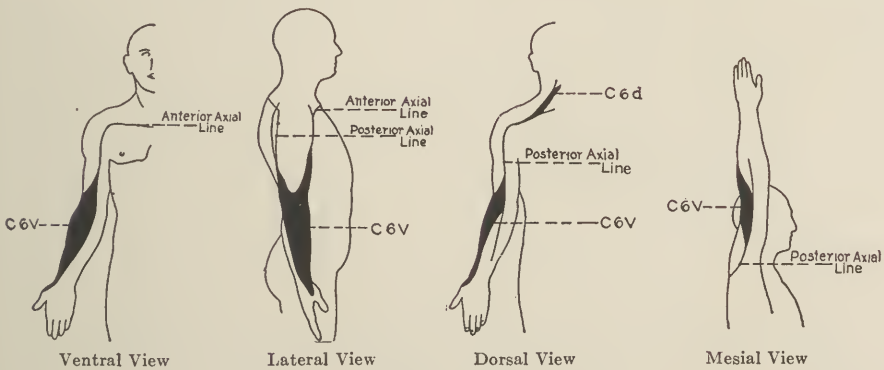


FIG. 178.—Sixth cervical dermatome.

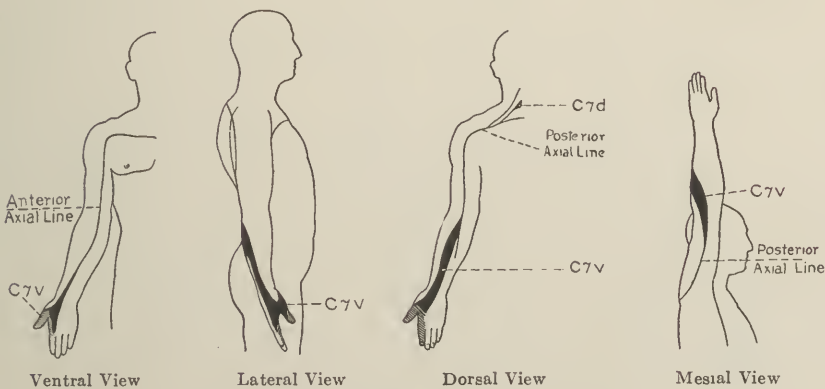


FIG. 179.—Seventh cervical dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
7th Cervical Ventral	Posterior external cutaneous branch of musculo-cutaneous nerve. Palmar cutaneous branches of median nerve and internal and external terminal branches of median nerve.	Narrow zone surrounding 6th cervical dermatome. Covers dorsum of thumb, index, middle and ring fingers in part.	7th Cervical
7th Cervical Dorsal	Posterior branch of 7th cervical nerve.	Interscapular triangle.	
8th Cervical Ventral	Terminal branches of the musculo-cutaneous nerve, collateral branch of the ulnar nerve, internal terminal branch of median nerve, external superficial palmar branch of ulnar nerve.	Covers anterior and posterior surfaces of forearm and a longitudinal zone on hand including index, middle, ring and little fingers, dorsal surface of ring and palmar surface of little fingers.	8th Cervical
8th Cervical Dorsal	Posterior branch of 8th cervical nerve.	Interscapular triangle.	

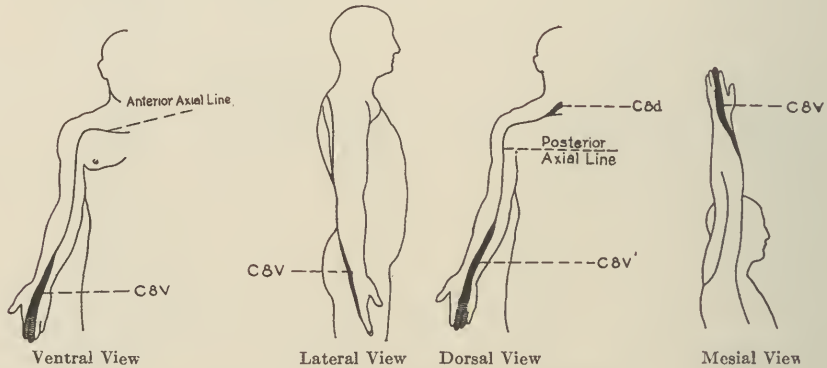


FIG. 180.—Eighth cervical dermatome.

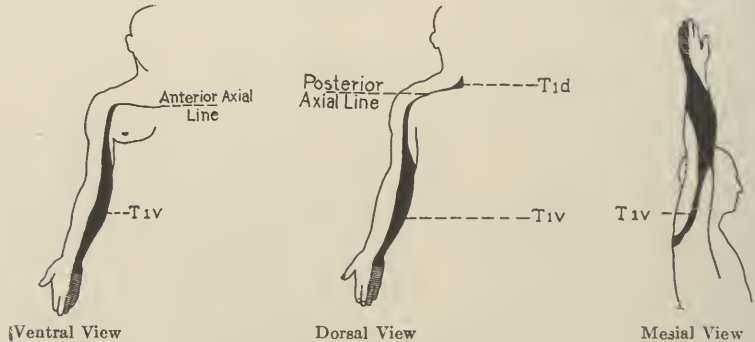


FIG. 181.—First thoracic dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
1st Thoracic Ventral	Communicating branch with the intercosto-humeral nerve, middle brachial cutaneous nerve, terminal branches of musculo-spiral nerve, dorsal cutaneous branch of ulnar, collateral branch of ulnar and the superficial palmar branch of ulnar.	Covers ulnar surfaces of hand, forearm and lower third of arm, in latter area extending from anterior to posterior axial lines.	1st Thoracic
1st Thoracic Dorsal	Posterior branch of 1st thoracic nerve.	Interscapular triangle.	
2nd Thoracic Ventral	Anterior and perforating branch and intercosto-humeral branch of 2nd intercostal nerve.	First thoracic zone with prolongation into postero-internal surface of arm. Ventral landmark, sternal insertion of 3rd rib.	2nd Thoracic
2nd Thoracic Dorsal	Posterior branch of 2nd thoracic nerve.	Dorsal landmark, 1st and 2nd thoracic spines.	
3rd Thoracic Ventral	Anterior and lateral perforating branches of 3rd intercostal nerve.	Second thoracic zone, small area in dorso-mesial surface of arm. Ventral landmark, 4th sterno-chondral junction.	3rd Thoracic
3rd Thoracic Dorsal	Posterior branch of 3rd thoracic nerve.	Dorsal landmark, the 3rd thoracic spine.	
4th Thoracic Ventral	Anterior and lateral perforating branches of 4th intercostal nerve.	Third thoracic zone. Ventral landmark, 4th sterno-chondral junction.	4th Thoracic
4th Thoracic Dorsal	Posterior branch of 4th thoracic nerve.	Dorsal landmark, 4th thoracic spine.	
5th Thoracic Ventral	Anterior and lateral perforating branches of 5th intercostal nerve.	Fourth thoracic zone. Ventral landmark, 5th and 6th sterno-chondral junctions.	5th Thoracic
5th Thoracic Dorsal	Posterior branch of 5th thoracic nerve.	Dorsal landmark, 6th thoracic spine.	
6th Thoracic Ventral	Anterior and lateral perforating branches of the 6th intercostal nerve.	Fifth thoracic zone. Ventral landmark, base of xyphoid cartilage.	6th Thoracic
6th Thoracic Dorsal	Posterior branch of 6th thoracic nerve.	Dorsal landmark, 7th thoracic spine.	

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
7th Thoracic Ventral	Anterior and lateral perforating branches of 7th intercostal nerve.	First abdominal zone. Ventral landmark, tip of xyphoid.	7th Thoracic
7th Thoracic Dorsal	Posterior branch of 7th thoracic nerve.	Dorsal landmark, 8th and 9th thoracic spine.	
8th Thoracic Ventral	Anterior and lateral perforating branches of 8th intercostal nerve.	Second abdominal zone, corresponds to middle of epigastric zone.	8th Thoracic
8th Thoracic Dorsal	Posterior branch of 8th thoracic nerve.	Dorsal landmark, 10th thoracic spine.	
9th Thoracic Ventral	Anterior and lateral perforating branches of 9th intercostal nerve.	Third abdominal zone, midway between xyphoid and umbilicus.	9th Thoracic
9th Thoracic Dorsal	Posterior branch of 9th thoracic nerve.	Dorsal landmark, 11th thoracic spine.	
10th Thoracic Ventral	Anterior and lateral perforating branches of 10th intercostal nerve.	Fourth abdominal zone, passes through umbilicus. Ventral landmark, umbilicus.	10th Thoracic
10th Thoracic Dorsal	Posterior branch of 10th thoracic nerve.	Dorsal landmark, 1st and 2nd lumbar spines.	
11th Thoracic Ventral	Anterior and lateral perforating branches of 11th intercostal nerve.	Fifth abdominal zone, midway between umbilicus and symphysis pubis.	11th Thoracic
11th Thoracic Dorsal	Posterior branch of 11th thoracic nerve.	Dorsal landmark, 2nd and 3rd lumbar spines.	

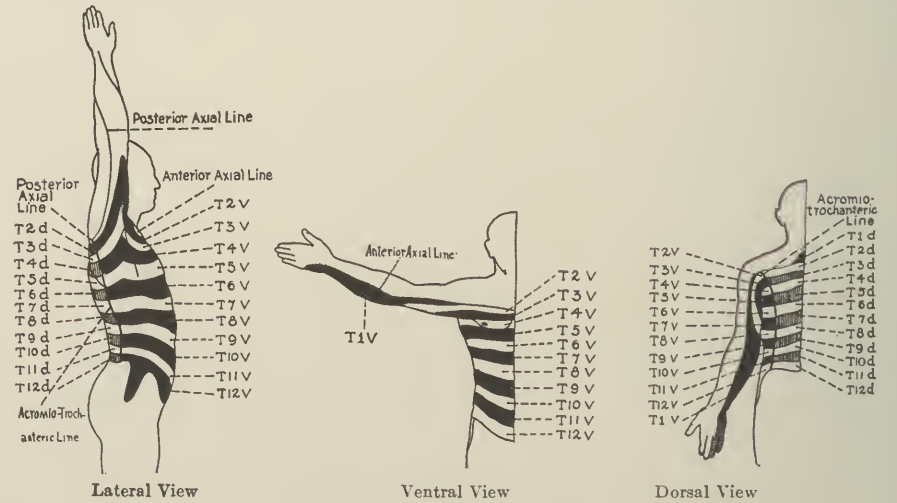


FIG. 182.—Thoracic dermatomes.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
12th Thoracic Ventral	Anterior and lateral perforating branches of 12th intercostal nerve.	Sixth abdominal zone, borders crest of ilium, Poupart's ligament, and sends a short extension into lateral area of thigh. Ventral landmark, symphysis.	12th Thoracic
12th Thoracic Dorsal	Posterior branch of 12th thoracic nerve.	Dorsal landmark, 4th and 5th lumbar spines.	
1st Lumbar Ventral	Ilio-inguinal and ilio-hypogastric, gluteal branch of the femoro-cutaneous nerve, lateral femoral cutaneous, crural branch of genito-crural nerve, inguinal and pudic branches from the ilio-inguinal and genito-crural nerves.	Dorsal to crural projection of 12th thoracic dermatome. Outermost area in quadrilateral zone, bounded ectally by acromio-trochanteric line, entally by external axial line of leg and coccygo-trochanteric line caudally. Ventral crural projection of 1st lumbar dermatome extends over root of penis.	1st Lumbar
1st Lumbar Dorsal	Posterior branch of 1st lumbar.	Dorsal and ventral zones continuous.	

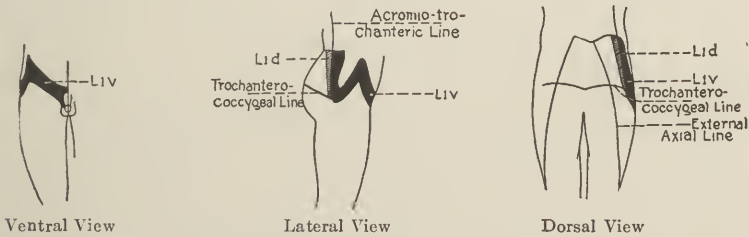


FIG.183.—First lumbar dermatome.

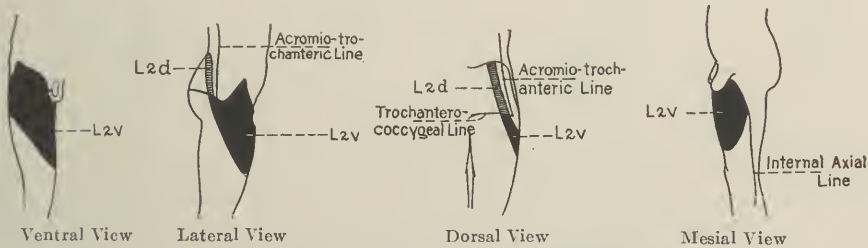


FIG. 184.—Second lumbar dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
2nd Lumbar Ventral	Gluteal and femoral branches of femoro-cutaneous nerve, superior and inferior cutaneous branches of internal musculo-cutaneous, cutaneous branch of obturator nerve, crural branch of genito-crural nerve and inguinal branches of ilio-inguinal and genito-crural nerve.	Extends from coccygo-trochanteric line downward, outward, forward, inward, then upward to internal axial line. Covers lateral, ventral and mesial surfaces of upper half of thigh. Mesial to 1st lumbar dermatome in area bounded by acromio-trochanteric and external axial lines.	2nd Lumbar
2nd Lumbar Dorsal	Posterior branch of 2nd lumbar nerve.	Dorsal and ventral zones continuous.	
3rd Lumbar Ventral	Lateral femoral cutaneous, inferior and superior perforating branches of the crural nerve, cutaneous branch of the tibial nerve and patellar branch of internal saphenous nerve.	Extends from coccygo-trochanteric line between 2nd lumbar dermatome and external axial line, across lower portion of ventral and mesial surfaces of thigh, including an area somewhat below knee up to internal axial line. Most mesial dermatome in quadrilateral space between acromio-trochanteric and external axial lines.	3rd Lumbar
3rd Lumbar Dorsal	Posterior branch of 3rd lumbar nerve.	Dorsal and ventral zones continuous.	

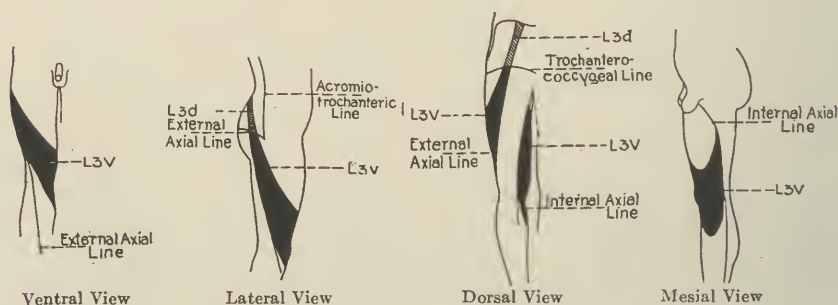


FIG. 185.—Third lumbar dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
4th Lumbar Ventral	Anterior and posterior branches of the internal saphenous nerve.	Extends from external axial line to internal axial line first along ventral surface, then upon mesial surface of leg as far down as ankle.	4th Lumbar
4th Lumbar Dorsal	Posterior branch of 4th lumbar nerve.	In intergluteal triangle. Dorsal and ventral zones are not continuous.	

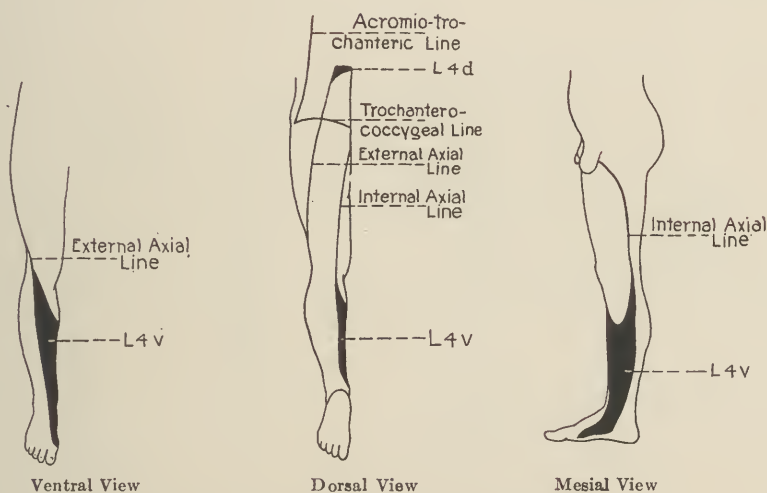


FIG. 186.—Fourth lumbar dermatome.

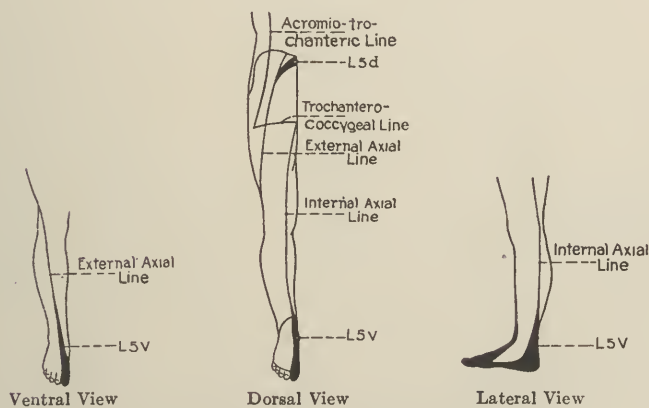


FIG. 187.—Fifth lumbar dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
5th Lumbar Ventral	External popliteal nerve, through the anterior tibial (tarsal branches, internal and dorsal digital branches), musculo-cutaneous nerve. Internal popliteal nerve, internal calcanean branches, supramalleolar branches and internal plantar branches.	Small area ventral and dorsal to internal malleolus, mesial half dorsum of foot including great toe. Mesial surface of heel and ball of foot and a small strip connecting these two along sole of foot.	5th Lumbar
5th Lumbar Dorsal	Posterior branch of 5th lumbar nerve.	In intergluteal triangle. Dorsal and ventral zones are not continuous.	
1st Sacral Ventral	External and internal popliteal nerves. Dorsal internal and median branches of musculo-cutaneous, external saphenous, external calcanean, external plantar, peroneal branch of external saphenous.	External surface of leg between internal and external axial lines below level of condyle of femur, lateral half surface of dorsum and sole of foot. Toes both surfaces.	1st Sacral
1st Sacral Dorsal	Posterior branch of 1st sacral nerve.	In intergluteal triangle. Dorsal and ventral zones are not continuous.	

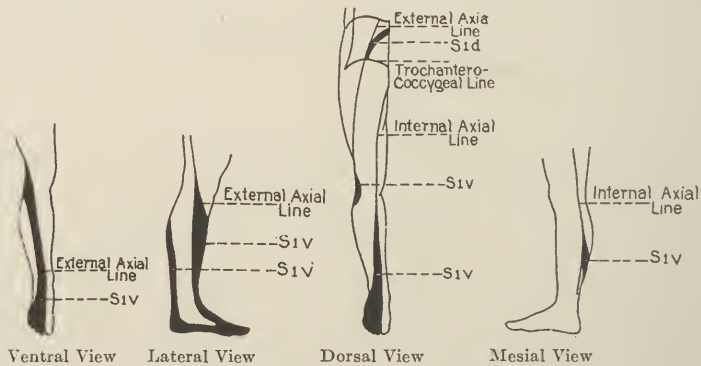


FIG. 188.—First sacral dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
2nd Sacral Ventral	Gluteal branches, femoropopliteal branches of the sciatic nerve, cutaneous peroneal branch of peroneal and sometimes musculo-cutaneous and external saphenous.	Dorso-lateral surface of leg from the intermalleolar line and along the posterior surface of thigh between internal and external axial lines up to coccygo-trochanteric line.	2nd Sacral
2nd Sacral Dorsal	Posterior branch of 2nd sacral nerve.	In intergluteal triangle. Dorsal and ventral zones continuous.	

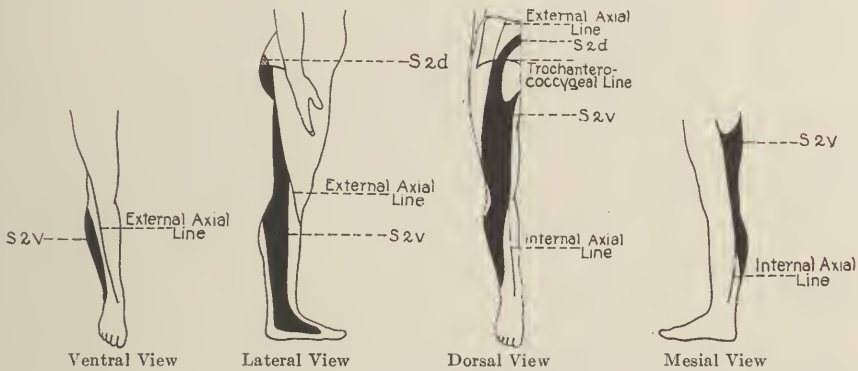


FIG. 189.—Second sacral dermatome.

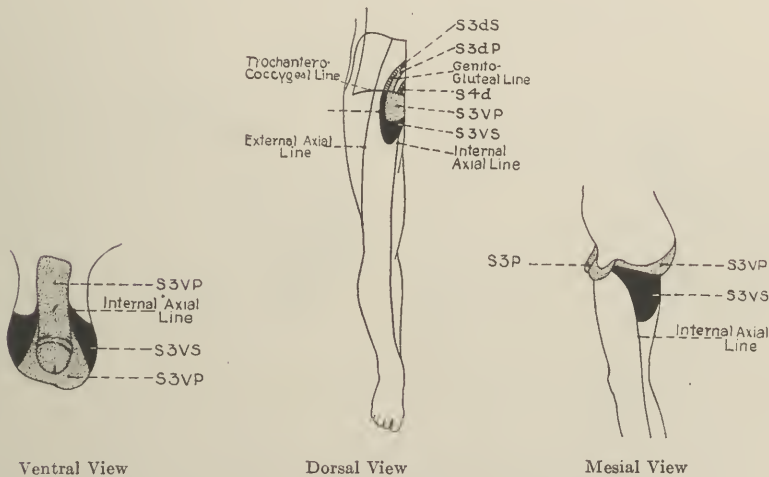


FIG. 190.—Third sacral dermatome.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
3rd Sacral Ventral	Internal pudic nerve by external and superficial branches of perineal nerve and dorsal nerve of penis.	Anterior portion of perineum, mesial portion of scrotum, and penis entire, skin and prepuce and mucosa of meatus, urethra in male. In female, clitoris and prepuce, labia majora and labia minora, external surface.	3rd Sacral
3rd Sacral Dorsal	Posterior branch of 3rd sacral nerve.	In intergluteal triangle. Dorsal and ventral zones continuous.	
4th Sacral Ventral	Collateral branches of perforating cutaneous of genital plexus, hemorrhoidal or anal cutaneous nerve. Anastomosis with internal pudic nerve.	Covers internal gluteal surface, internal gluteal sulcus and posterior portion of perineum as far back as skin over bulb of urethra in male and the fourchette of vagina in female.	4th Sacral
4th Sacral Dorsal	Posterior branch of 4th sacral nerve.	In intergluteal triangle. Ventral and dorsal zones continuous.	
5th Sacral Ventral	Coccygeal nerve.	Covers skin over tip of coccyx, its posterior surface as far forward as anus.	5th Sacral
5th Sacral Dorsal	Posterior branch of 5th sacral nerve.		

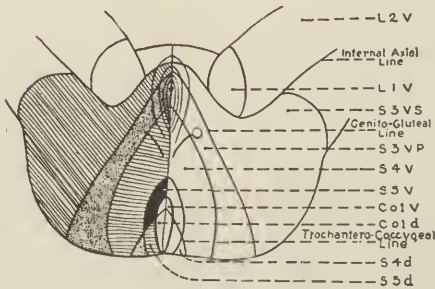


FIG. 191.—Perineal dermatomes in the female.

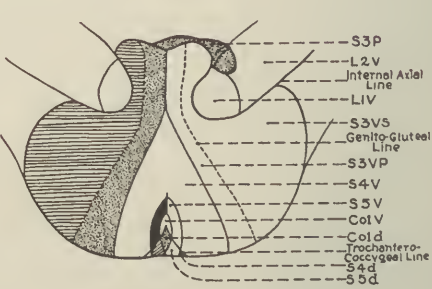


FIG. 192.—Perineal dermatomes in the male.

Dermatome	Nerve or nerves to which this area of innervation corresponds	Area supplied by dermatome and general landmarks in its topography	Dorsal nerve root corresponding to dermatome
1st Coccygeal Ventral	Coccygeal nerve.	Covers skin over tip of coccyx, its posterior surface as far forward as anus.	1st Coccygeal
1st Coccygeal Dorsal	Posterior branch of 1st coccygeal nerve.		

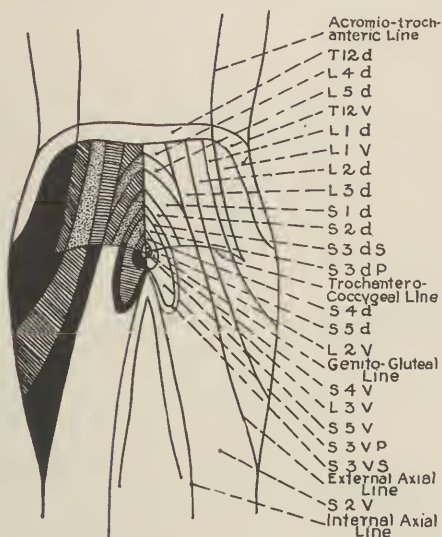


FIG. 193.—Dermatomes in the gluteal and perineal regions.

TABLE OF THE MUSCLES SUPPLIED BY THE SEVERAL SPINAL NERVES. (*Quain.*)**First Cervical Segment**

Through Ventral Division of First Cervical Nerve. Rectus lateralis, Rectus capitis anticus minor and major, Geniohyoid, Infrahyoid muscles.

Through Dorsal Division of the First Cervical Nerve. Rectus capitis posticus major and minor, Obliquus superior and inferior, Complexus.

Second Cervical Segment

Through Ventral Division of the Second Cervical Nerve. Rectus capitis anticus major, Longus colli, Sterno-cleido-mastoid, Geniohyoid, Infrahyoid muscles, Trapezius.

Through Dorsal Division of the Second Cervical Nerve. Obliquus inferior, Complexus, Splenius, Trachelo-mastoid.

Third Cervical Segment

Through Ventral Division of the Third Cervical Nerve. Rectus capitis anticus major, Longus colli, Infrahyoid muscles, Scalenus medius, Levator angulæ scapulæ, Sterno-cleido-mastoid, Trapezius, Diaphragm, Infrahyoid muscles.

Through Dorsal Division of the Third Cervical Nerve. Complexus, Transverso-spinales, Splenius, Erector spinæ.

Fourth Cervical Segment

Through Ventral Division of the Fourth Cervical Nerve. Rectus capitis anticus major, Longus colli, Scalenus medius (and anticus), Diaphragm, Levator angulæ scapulæ, Trapezius.

TABLE OF THE MUSCLES SUPPLIED BY THE SEVERAL SPINAL NERVES (*Continued*)

Through Dorsal Division of the Fourth Cervical Nerve. Complexus, Transverso-spinales, Splenius, Erector spinæ.

Fifth Cervical Segment

Through Ventral Division of Fifth Cervical Nerve. Longus colli, Scaleni, (Diaphragm), Levator angulæ scapulæ, Rhomboidei, Serratus magnus, Subclavius, Supraspinatus, Infraspinatus, Teres minor, Subscapularis, (Teres Major), Deltoid, Triceps, (Pectoralis major), Biceps, Brachialis anticus, Extensores carpi radiales.

Through Dorsal Division of Fifth Cervical Nerve. Transverso-spinales, Erector spinæ.

Sixth Cervical Segment

Through Ventral Division of Sixth Cervical Nerve. Longus colli, Scaleni, (Subclavius), Serratus magnus, (Supraspinatus, Infraspinatus, Teres minor), Subscapularis, Latissimus dorsi, Teres major, Deltoid, Pectoralis major, Triceps, Biceps, Brachialis anticus, Pronator radii teres, Flexor carpi radialis, Brachioradialis, Extensores carpi radiales, Abductor, Opponens, and Flexor brevis pollicis.

Through Dorsal Division of Sixth Cervical Nerve. Transverso-spinales, Erector spinæ.

Seventh Cervical Segment

Through Ventral Division of Seventh Cervical Nerve. Longus colli, Scalenus medius, (Serratus magnus), Pectoralis major and minor, Latissimus dorsi (Teres major), Coraco-brachialis, Triceps brachii, Anconeus, Flexor sublimis digitorum, (Flexor profundus digitorum, Flexor longus pollicis, Pronator quadratus), Extensores radiales, Extensors of digits, Extensor carpi ulnaris.

Through Dorsal Division of Seventh Cervical Nerve. Transverso-spinales, Erector spinæ.

Eighth Cervical Segment

Through Ventral Division of Eighth Cervical Nerve. Longus colli, Pectoralis major and minor, Latissimus dorsi, Triceps brachii, Anconeus, Flexors of digits, Flexor carpi ulnaris, Pronator quadratus, Adductores pollicis, Interossei, Abductor, Flexor brevis, and Opponens digiti quinti.

Through Dorsal Division of Eighth Cervical Nerve. Transverso-spinales, Erector spinæ.

First Thoracic Segment

Through Ventral Division of First Thoracic Nerve. Pectoralis major and minor, Flexors of digits, Flexor carpi ulnaris, Pronator quadratus, Intercostales, Levator costæ, Serratus posticus superior, Abductor, Flexor brevis, and Opponens digiti quinti.

Through Dorsal Division of First Thoracic Nerve. Transverso-spinales, Erector spinæ.

Second Thoracic Segment

Through Ventral Division of Second Thoracic Nerve. Intercostales, Levatores costarum, Serratus posticus superior, (Triangularis sterni).

Through Dorsal Division of Second Thoracic Nerve. Transverso-spinales, Erector spinæ.

Third and Fourth Thoracic Segments

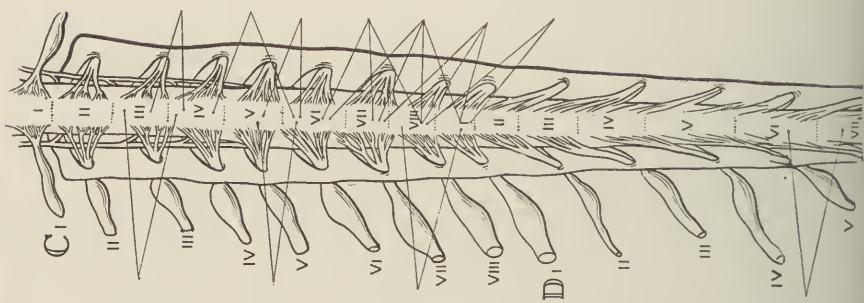
Through Ventral Division of Third and Fourth Thoracic Nerves. Intercostales, Levatores costarum, Serratus posticus superior, Triangularis sterni.

TABLE OF THE MUSCLES SUPPLIED BY THE SEVERAL SPINAL NERVES (*Continued*)

<i>Through Dorsal Division of Third and Fourth Thoracic Nerves.</i>	Transverso-spinales, Erector spinæ.
Fifth and Sixth Thoracic Segments	
<i>Through Ventral Division of Fifth and Sixth Thoracic Nerves.</i>	Intercostales, Levatores costarum, Triangularis sterni, Obliquus externus, Rectus abdominis.
<i>Through Dorsal Division of Fifth and Sixth Thoracic Nerves.</i>	Transverso-spinales, Erector spinæ.
Seventh and Eighth Thoracic Segments	
<i>Through Ventral Division of Seventh and Eighth Thoracic Nerves.</i>	Intercostales, Levatores costarum, Subcostales, Obliquus externus, Obliquus internus, Transversalis abdominis, Rectus abdominis
<i>Through Dorsal Division of Seventh and Eighth Thoracic Nerves.</i>	Transverso-spinales, Erector spinæ.
Ninth, Tenth and Eleventh Thoracic Segments	
<i>Through Ventral Division of Ninth, Tenth and Eleventh Thoracic Nerves.</i>	Intercostales, Levatores costarum, Subcostales, Serratus posticus inferior, Obliquus externus, Obliquus internus, Transversalis abdominis, Rectus abdominis.
<i>Through Dorsal Division of Ninth, Tenth and Eleventh Thoracic Nerves.</i>	Transverso-spinales, Erector spinæ.
Twelfth Thoracic Segment	
<i>Through Ventral Division of Twelfth Thoracic Nerve.</i>	(Quadratus lumborum), Obliquus externus, Obliquus internus, Transversalis abdominis, Rectus abdominis, Pyramidalis.
<i>Through Dorsal Division of Twelfth Thoracic Nerve.</i>	Transverso-spinales, Erector spinæ.
First Lumbar Segment	
<i>Through Ventral Division of First Lumbar Nerve.</i>	Quadratus lumborum, (Obliquus internus, Transversalis abdominis), Cremaster.
<i>Through Dorsal Division of First Lumbar Nerve.</i>	Transverso-spinales, Erector spinæ.
Second Lumbar Segment	
<i>Through Ventral Division of Second Lumbar Nerve.</i>	(Quadratus lumborum), Cremaster, Psoas magnus, (Psoas parvus), Iliacus, Pectineus, Adductor longus, Adductor brevis, Gracilis, Sartorius.
<i>Through Dorsal Division of Second Lumbar Nerve.</i>	Transverso-spinales, Erector spinæ.
Third Lumbar Segment	
<i>Through Ventral Division of Third Lumbar Nerve.</i>	Psoas magnus, Iliacus, Pectineus, Adductor longus, Adductor brevis, Adductor magnus, Gracilis, Obturator externus, Sartorius, Quadriceps.
<i>Through Dorsal Division of Third Lumbar Nerve.</i>	Multifidus spinæ, Erector spinæ.
Fourth Lumbar Segment	
<i>Through Ventral Division of Fourth Lumbar Nerve.</i>	(Psoas magnus), Adductor brevis, Adductor magnus, Gracilis, Obturator externus, Quadriceps, Gluteus medius and minimus, Tensor fasciæ latæ, (Gluteus

Fig. 194.—CUTANEOUS AND MUCOUS REFLEXES. (*Déjerine.*)

Reflex Contraction	Seat of Excitation	Name of Reflex	Name of Reflex	Reflex Contraction
Contraction of the diaphragm, retraction of the epigastric region	Excitation of the mammary region	Reflex of the diaphragm C ³ , C ⁴	Reflex of the sternocleidomastoid C ³ , C ⁴	Contraction of the muscle
Contraction of the muscles of the shoulder	Excitation of the skin of the sub-scapular region	Scapular reflex C ³ , C ⁶	Bicipital reflex C ⁴ , C ⁵ , C ⁶	Flexion of the forearm on the arm
Flexion of the fingers in the hand	Tickling of the palm of the hand	Palmar reflex C ⁵ , T ¹	Peristernal reflex C ⁵ , C ⁶	Flexion of the forearm on the arm
			Brachial triceps reflex C ⁶ , C ⁷ , C ⁸	Extension of the forearm on the arm
			Ulnar reflex C ⁶ , C ⁷ , C ⁸ , T ¹	Pronation movement of the forearm and of the hand
			Scapular reflex C ⁷ , T ¹	Contraction of the pectoralis major. Adduction of the hand
Contraction of the entire upper part of the rectus muscle	Tickling of the skin of the epigastric region	Epigastric or upper abdominal reflex T ⁶ , T ⁷	Reflex of the flexors C ⁸ , T ¹	Flexion of the fingers on the hand



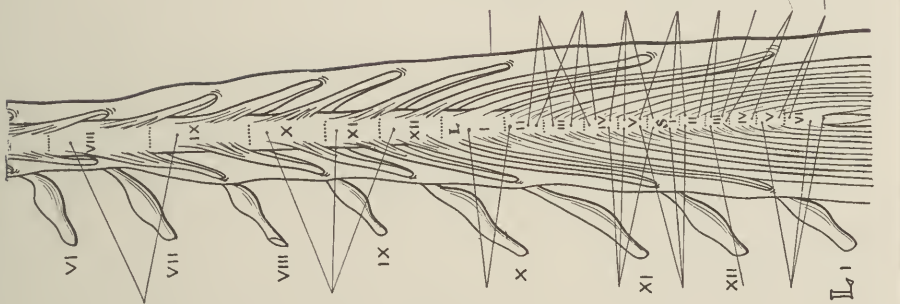
Contraction of inferior part of external rectus and rectus abdominus muscles	Excitation of the skin of the region above the umbilicus	Middle abdominal or supra-umbilical reflex T^8, T^9		Superior ejaculation center L^1, L^2 Periosteal reflex of adductors L^2, L^3, L^4 Patellar reflex L^2, L^3, L^4 Biceps reflex of L^4, L^5, S^1 Achilles reflex L^5, S^1, S^2 Erection Center S^2 Lower ejaculation center S^3 Rectal and vesical centers S^4, S^5 Anal center S^5, C^1	Percussion of adductor magnus tendon Percussion of the patellar tendon Percussion of the head of the fibula Percussion of the tendo Achilles	Adductor movement of the thigh Extension of the leg on the thigh Flexion movements of the thigh Plantar flexion of the foot
Contraction of the lower parts of the abdominal muscles	Excitation of the skin of the region below the umbilicus and of the entire upper and external part of the inguinal region	Lower abdominal or infra-umbilical reflex T^{10}, T^{11}, T^{12}				
Elevation of the testicle toward the ring	Excitation of the skin of the upper part of the inner surface of the thigh	Cremasteric reflex L^1, L^2, L^3, S^1				
Contraction of the gluteal muscles	Excitation of the skin of the buttock	Buttock or gluteal reflex L^4, L^5, S^1				
Plantar flexion of the great toe and contraction of the tensor fasciae femoris	Excitation of the skin of the sole of the foot	Plantar reflex L^5, S^1, S^2				
Contraction of the bulbo-cavernosus muscles	Pinching of glans or skin of the dorsal surface of penis	Bulbo-cavernosus reflex S^3				
Contraction of the sphincter ani	Tickling of the cutaneous surface of the edge of the anus	Anal reflex S^5, C^1				

TABLE OF THE MUSCLES SUPPLIED BY THE SEVERAL SPINAL NERVES (*Continued*)

	maximus, Obturator Internus), Quadratus femoris. Semimembranosus, (Deep muscles of back of leg), Muscles of front and outer side of leg, Extensor brevis digitorum.
<i>Through Dorsal Division of Fourth Lumbar Nerve.</i>	Multifidus spinæ, Erector spinæ.
Fifth Lumbar Segment	
<i>Through Ventral Division of Fifth Lumbar Nerve.</i>	(Quadriceps), Adductor magnus, Gluteus maximus, medius and minimus, Tensor fasciæ latæ, (Pyriformis), Quadratus femoris, Obturator internus, Ham-strings, Muscles of leg (except gastrocnemius), Extensor brevis digitorum, Inner muscles of sole.
<i>Through Dorsal Division of Fifth Lumbar Nerve.</i>	Multifidus spinæ, Erector spinæ.
First Sacral Segment	
<i>Through Ventral Division of First Sacral Nerve</i>	Gluteus maximus, medius, and minimus, Tensor fasciæ latæ, Pyriformis, Obturator internus, Quadratus femoris, (Adductor magnus), Ham-strings, Muscles of leg and foot.
<i>Through Dorsal Division of First Sacral Nerve.</i>	Multifidus spinæ.
Second Sacral Segment	
<i>Through Ventral Division of Second Sacral Nerve. †</i>	Gluteus maximus, (Gluteus medius and minimus), Tensor fasciæ latæ, Pyriformis, Obturator internus, Semitendinosus, Biceps, (Muscles of front of leg, Peronei), Gastrocnemius, Soleus, Flexor longus hallucis, (Flexor longus digitorum, Tibialis posticus), Outer muscles of sole, Perineal muscles.
<i>Through Dorsal Division of Second Sacral Nerve.</i>	Multifidus spinæ.
Third Sacral Segment	
<i>Through Ventral Division of Third Sacral Nerve.</i>	(Pyriformis), Biceps, long head, (Gastrocnemius, Soleus, Muscles of Sole), (Levator ani Coccygeus), Perineal muscles.
<i>Through Dorsal Division of Third Sacral Nerve.</i>	Multifidus spinæ.
Fourth Sacral Segment	
<i>Through Ventral Division of Fourth Sacral Nerve.</i>	Levator ani, Coccygeus, Perineal muscles.
Fifth Sacral Segment	
<i>Through Ventral Division of Fifth Sacral Nerve.</i>	(Coccygeus).

Names enclosed in parentheses indicate that the muscles are not always supplied from the nerve-root in question.

CHAPTER XI

THE SPINAL CORD

THE FUNCTION OF THE WHITE MATTER IN THE CORD SEGMENT

The General Arrangement and Significance of the White Matter of the Spinal Cord. The white matter or medullary substance bears a constant and characteristic relation to the gray matter in all of the segmental portions of the central nervous system. The myelinated fibers form an investment about the gray matter which, from the nature of its position, serves to limit the expansion of the gray substance: In those parts of the nervous system, on the other hand, where expansion of the cell-containing substance has been the paramount issue, the structural design departs from this more primitive arrangement. The nerve-cells take up a position outside of the medullary substance where they may multiply and expand their connections without the embarrassment of a large mass of surrounding white matter. This difference in the relations of the gray to the white matter in the central nervous system affords one of the major points of differentiation between the two principal sets of organs which constitute the neuraxis. In the segmental organs, represented in the spinal cord and the brain stem, the gray matter occupies a central position and is surrounded by the white matter. In the portions of the central nervous system which have developed as additions to the segmented structures and which are, therefore, known as the *suprasegmental organs*, the relation of the gray to the white matter is reversed, the cell-containing substance occupying a position outside of the medullary substance. This is true of the cortex of the cerebellum, of the tectum mesencephali and of the cerebral cortex. The central position of the gray matter in the segmental portions of the central nervous system indicates the ultimate achievement of centralized control. The nerve cells under these circumstances are most advantageously placed in relation to each other and accomplish their intercommunications in the most economical manner. The position of the white matter became subordinate in the process of centralization. The connecting fibers, in order that they might not disturb this process, have taken up positions ectal to the cell-containing mass. Such an arrangement, while in the interest of the centralization of power in the gray matter, has placed obvious restrictions upon the expansion of this substance. It has limited the potentiality of expansion and deprived the gray matter of still further evolutionary possibilities. The important advances leading up to the development of the most efficient behavioral reactions, have not been dependent upon expansion in the segmental portions of the nervous system. Such progressive advances have come as a result of the extensive growth in the suprasegmental structures

already mentioned. It is evident, on the other hand, that however great this suprasegmental expansion may be, it would prove ineffectual unless it could exert its influence directly upon the segmented portions of the central nervous system. In consequence, there have come into existence collections of nerve fibers which establish intimate connections between the segmental and suprasegmental portions of the neuraxis. These connecting fibers, however, follow the general law observed by axones in the spinal cord and brain stem in assuming positions outside of the gray matter.

Groups of Fibers of the White Matter with Reference to the Connections Which They Establish. Three groups of nerve fibers may be distinguished in the white matter according to the connections which they establish. They are (1) intrasegmental fibers; (2) intersegmental fibers, and (3) suprasegmental fibers.



FIG. 195.—The white columns of the spinal cord. Red indicates the lateral column. Blue indicates the ventral column. Green indicates the dorsal column. About the entrance of the dorsal root is a stippled area, the zone of Lissauer.

The position of the individual fiber in the white matter is determined by the length of the course which it must pursue to make its necessary connections. The shorter its course, the nearer to the gray matter will be the axone. Axones whose origin and destination lie within the same segment, *i.e.*, intrasegmental fibers, will be contiguous with the gray matter. Short intersegmental fibers occupy positions immediately peripheral to the intrasegmental fibers. The long intersegmental fibers, as well as the suprasegmental fibers, occupy positions at a greater distance from the gray

matter. This rule, subject to minor variations, indicates the general locations in cross section of the three groups of fibers entering into the white matter.

The Three White Columns of the Cord. Each half of the spinal cord presents in its white matter three well-defined columns, namely, (1) *the dorsal column*; (2) *the lateral column*, and (3) *the ventral column*.

THE DORSAL COLUMN is bounded mesially by the dorso-median septum, and laterally by the most ventral fibers in the entrance zone of the dorsal root.

THE LATERAL COLUMN is the portion of the white matter comprised between the entrance zone of the dorsal roots and the emergent zone of the ventral roots.

THE VENTRAL COLUMN is all that portion of the white matter mesial to the ventral root fibers.

CONSTITUENTS OF THE DORSAL WHITE COLUMN

The fibers which constitute the dorsal white column are intrasegmental and intersegmental in character. The *intrasegmental fibers* occupy a juxtaposed position, that is to say, next to the gray matter, and are particularly close to the median fissure and the gray commissure. They take origin in the dorsal gray column and follow an ascending as well as a descending course. Some of them run upward, others downward, for relatively short distances, ultimately to enter the gray matter. Their function is to serve the purposes of intrasegmental association. By this means many cells of the same segment of the spinal cord are brought into active relation with each other.

Intersegmental Fibers in the Dorsal White Column. The larger portion of the fibers of the dorsal white column are intersegmental, and two chief varieties are distinguished, the *spino-bulbar intersegmental fibers* and the *spino-spinal intersegmental fibers*.

THE SPINO-BULBAR INTERSEGMENTAL FIBERS. These fibers extend a relatively much longer distance than the spino-spinal fibers. They occupy more than four-fifths of the dorsal white column. Their fasciculi are separated from the gray matter in the region of the commissure by the interposition of the intrasegmental fibers. They are separated from the dorsal horn by the entering fibers of the dorsal roots, and with a certain slight irregularity to be observed later, they extend to the dorsal periphery of the cord.

Origin of the Spino-Bulbar Fibers in the Dorsal White Column. The origin of these fibers is in the dorsal root ganglion cells, whose proximal processes form the dorsal roots. These roots enter the cord in the *entrant root zone* in such a way that the axones sweep forward and inward toward the mesial surface of the base of the dorsal gray column. In the entrant root zone, each axone divides into a long ascending and a short descending branch. Immediately after this division, the ascending branch takes up a position contiguous with the fibers of the entrant zone and begins to ascend toward the brain. Upon entering the segment next above, it en-

counters the entering fibers of the dorsal root next higher in order. In consequence of the ascending branches given off by these root fibers, the branch from the lower segment is pushed inward toward the median line. Each successive group of entrant zone fibers, giving off its own ascending branches, causes the fibers entering lower down to move closer toward the dorso-median septum. In this manner the fibers which come in at the level of the sacral segments lie close to the dorso-median septum in the cervical region, while the fibers coming in from the cervical segments are nearer the entrant root zone.

Tracts Formed by the Spino-Bulbar Fibers of the Dorsal White Column. All of these fibers are heavily myelinated. Upon reaching the levels of the cervical enlargement, the long ascending intersegmental axones become subdivided into two distinct groups by a partition of connective tissue which extends inward from the dorso-paramedian sulcus toward the gray commissure. This partition is the *dorso-paramedian septum*. It divides the dorsal white column into two fasciculi or tracts, the *tract of Goll* or *fasciculus gracilis*, and the *tract of Burdach* or *fasciculus cuneatus*. The division of the dorsal white column into these two tracts, although most conspicuous in the cervical region, may also be made out in the upper thoracic segments. In the lower thoracic, lumbar and sacral segments this subdivision of the dorsal white column disappears. The significance of the two fasciculi constituting the spino-bulbar portion of the dorsal white column is evident. The axones coming from the coccygeal, sacral, lumbar and lower thoracic spinal ganglia represent sensory areas of the lower extremities, external genitals and lower portion of the trunk. Successive migration of these collaterals as they ascend toward the brain determines their mesial position upon reaching the level of the cervical enlargement, and hence the tract of Goll consists of sensory fibers from the leg, genitals and lower portion of the trunk. The fibers comprising the tract of Burdach have their origin in the spinal ganglia of the upper thoracic and cervical regions, and represent sensory areas of the upper trunk, arm and neck. They occupy a position lateral to the tract of Goll.

Myelinogenetic Fields in the White Substance. It is the opinion of several authorities that the tracts of the spinal cord, during the process of development, do not convey nerve impulses until they have received their myelin sheaths. Upon this basis the theory has been constructed that the more fundamental bundles in the white matter receive their myelin sheaths at an early period. According to Flechsig, three portions of the tract of Goll may be recognized according to the time of myelination. These divisions are known as the *myelinogenetic fields of Flechsig*. The first of these fields to receive its myelin sheath is the ventral area extending forward almost to the gray commissure. A small area mesial to it is known as the *mesial myelinogenetic field*, and a third larger field of this kind called the dorso-median is present immediately beneath the periphery of the dorsal column. Between the dorso-median and ventral areas is the median myelinogenetic field. The dorso-median field receives its myelin sheath near the end of the

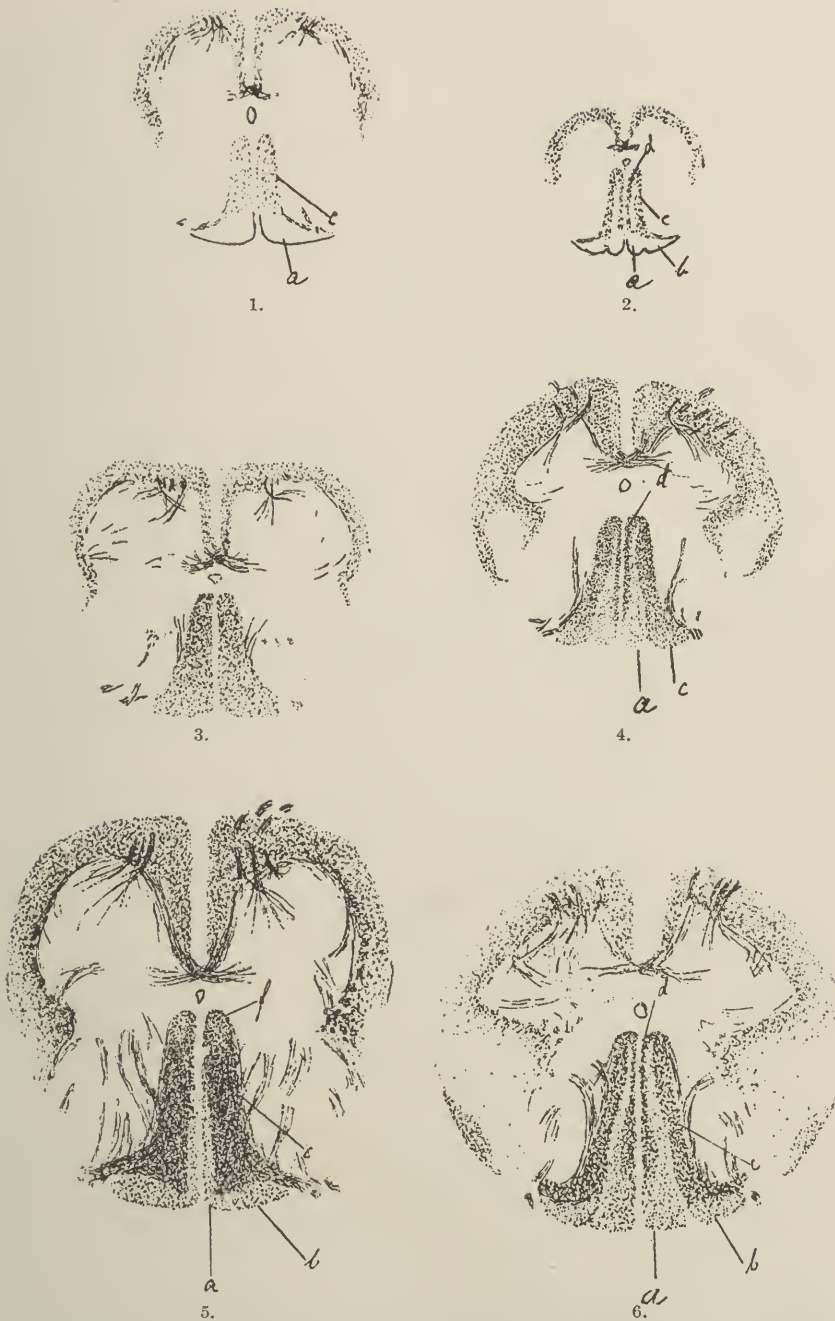


FIG. 196.—Diagrams showing the myelinogenetic fields of the spinal cord at the different periods of fetal life. (*Trepinski.*)

1. Lumbar cord at the fifth month. 2. Cervical cord at the fifth month. 3. Lumbar cord at five and a half months. 4. Cervical cord at five and a half months. 5. Lumbar cord at the seventh month. 6. Cervical cord at the seventh month.

a—Dorso-median root zone. b—Dorso-lateral root zone. c—Anterior root zone. d—Median zone.

seventh fetal month, and myelinization is nearly complete in the ventral field at the end of the fifth month. The mesial field completes its myeliniza-

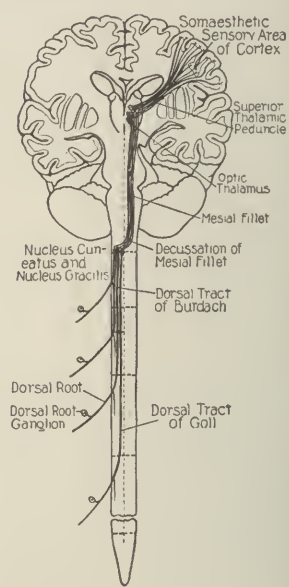
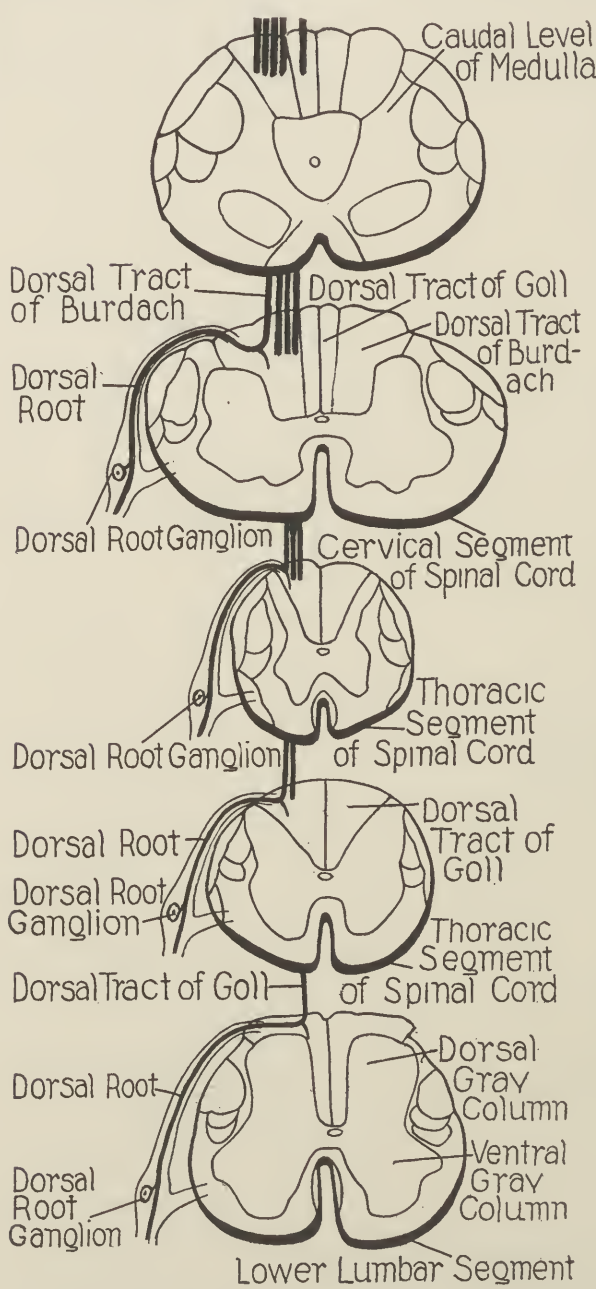


FIG. 197.—The dorsal tracts of Goll and Burdach passing through the spinal cord and representing the spinal division of the spino-thalamo-cortical pathway. The tracts serve for the conduction of discriminative somesthetic impulses from the skin, muscles, joints and bones.

tion during the fifth month and the median field is completely myelinated by the end of five and one half months of fetal life. Trepinski identifies

four fetal fields in the dorsal column and has called attention to the parallelism which seems to exist between the physiological myelinization during embryonic life and the pathological degeneration of the dorsal column which occurs in *tabes dorsalis*. Flechsig also recognized myelinogenetic areas in the tract of Burdach in which he was able to distinguish a ventral, a middle and a dorsal field, each of which received its myelin sheath at a different period of development. As a whole, the tract of Burdach undergoes myelinization at a relatively late period, *i.e.*, at the end of the seventh fetal month or near the beginning of the eighth month. It is remarkable in certain cases of *tabes dorsalis* to note the manner in which the degeneration of the dorsal column fibers in the tracts of Goll and Burdach follow the order of myelinization observed during development. The fibers first myelinated are first to degenerate, while those which receive their myelin sheath later show a degenerative change at a subsequent period in the disease.

Course of the Tracts of Goll and Burdach. The tract of Goll continues its ascent from the lower segments of the cord to the medulla oblongata; the tract of Burdach, beginning in the upper thoracic segments, passes upward, receives increments as it ascends, and finally ends in the medulla. Both of these tracts convey afferent impulses toward the brain. Were it not for the fact that they receive a relay in the medulla oblongata, the impulses which they conduct would fall short of their goal. In the medulla, each of these tracts comes into synaptic relation with a special nucleus which serves as a relay station on the way toward the brain. The tract of Goll ends in the *nucleus gracilis*, while the tract of Burdach has its termination in the *nucleus cuneatus*. Both of these nuclei will be described in the discussion of the medulla oblongata.

Functions of the Tracts of Goll and Burdach. Although it is clear that the tracts of Goll and Burdach convey afferent impulses, a more precise understanding of their type is necessary. It is to be borne in mind that the fibers of these tracts remain ipsilateral throughout their entire course in the spinal cord. Whatever impulses they convey must, therefore, come from the corresponding half of the body. It has been shown by clinical observation and by pathological control of carefully studied cases that the fibers ascending in the tracts of Goll and Burdach conduct special types of sensibility. Important among these sensory impulses are those concerned in the muscle and joint sensibility, *bathesthetic sensibility*. Even this is scarcely enough to distinguish the types of sensory impulses which pass by way of the dorsal column. Experience teaches that only a certain quality of muscle and joint sensibility ascends in this position toward the brain, *i.e.*, that quality of sensory impulses which has to do with muscle and joint discrimination. Muscular activity without this discriminative direction becomes irregular and incoordinate, while the movements entering into motor action are either excessive or inadequate. Such is the case, for example, in *tabes dorsalis*, in which disease the patient presents an actual locomotor ataxia. In performing skilled acts with the upper extremities he often manifests an inexactitude in the execution of his motor activities.

Another type of discriminative sensibility, *tactile discrimination*, also makes its way upward in the dorsal column. By means of this sense quality the individual is able to localize the point of contact upon the skin with a certain degree of exactness. His accuracy depends upon the area of skin stimulated. Localization on the balls of the fingers, upon the surface of the hands and on the tips of the toes is accurate within the limits of about one-half centimeter. This distance becomes greatly increased upon other surfaces of the body in which discrimination is of less value to the individual.

By means of tactile discrimination, it is possible to recognize the difference in distance between two points coming in contact with the skin. This is tested by a compass or pair of dividers. The distances between the two points constitute the radii of circles which are known as the *circles of Weber*. In parts of the skin most employed in the critical activities of sensibility, the circles of Weber are relatively small, the radii varying from one-quarter to one-half a centimeter. In other parts of the body where such discrimination is less useful, the circles of Weber are large, their radii varying from one to four centimeters.

Pressure Sensibility (Piezesthesia). Impulses necessary to pressure discrimination are also conveyed toward the brain in the columns of Goll and Burdach.

Vibratory Sensibility (Pallesthesia). This also is probably a discriminative type of sensibility conducted by the columns of Goll and Burdach. In general, the spino-bulbar fibers in the dorsal white column convey impulses of *all forms* of discriminative somesthetic sensibility.

THE SPINO-SPINAL INTERSEGMENTAL FIBERS. These fibers are of two varieties, those which ascend, and those which form well-marked bundles of descending axones. Descending intersegmental fibers appear in the dorsal column in relatively small numbers; they occupy different positions at different levels of the cord.

In the sacral region, these fibers are collected in a small strand at the dorso-mesial angle of the column and constitute the *triangular bundle of Philippe-Gombault*.

In the lumbar region, they appear as a semi-oval area adjacent to the dorso-median septum. This is the *oval bundle of Flechsig*.

In the cervical and thoracic regions of the cord, the descending spino-spinal fibers are more scattered and do not form discrete bundles as in the lower segments. One bundle of this variety is situated contiguous to the gray matter at the junction of the dorsal horn and the commissure. This is the *cornu-commissural bundle of Bruce*.

Another small descending fasciculus in the dorsal white column appears at about the middle of this region in the form of a comma-shaped collection of fibers. It is most prominent in the thoracic portion of the cord and is known as the *comma tract of Schultze*. It is believed that its fibers either originate in cells of the gray matter in the dorsal column or else are descending collaterals from the axones of the dorsal roots.

All the descending intersegmental spino-spinal tracts, with the possible exception of the fibers forming the comma tract of Schultze, take origin in cells situated in the gray matter. They pass downward from one to three segments of the cord, and some extend even a greater distance; many of these fibers turn into the gray matter in order to establish intersegmental associations between cells of their own segment and other cells in segments occupying more caudal positions.

The Tract of Lissauer. Most of the fibers of the dorsal column are heavily myelinated and are derived either from the mesial entrance zone of the



FIG. 198.—Spino-spinal intersegmental fibers. Blue indicates the triangular bundle of Philippe-Gombault. Green indicates the oval bundle of Flechsig.

dorsal roots or from the tract cells in the gray matter of the spinal cord. One bundle of fibers, however, is made up of lightly myelinated axis cylinders which enter the cord in the lateral entrant zone immediately opposite the apex of the dorsal horn. These axones, upon entering, split in a T-shaped fashion into an ascending and a descending branch, which form the *tract of Lissauer*. The ascending branches pass two or three segments upward as the tract of Lissauer and dip into the gray matter to end about cells in the substantia gelatinosa of Rolando. The synapsis accomplished in this position brings the tract of Lissauer into relation with tract cells which send their axones across the gray matter in such a manner that they traverse the gray commissure to the opposite half of the cord and from this point pass outward into the lateral white column where they turn cranially to form the *spino-thalamic tract*. The axones in the tract of Lissauer, like other dorsal root axones,

take origin in the cells of the spinal ganglia. They form the chief constituents of the lateral entrant zone and may be easily recognized in cross section because their axis cylinders are provided with a scant covering of myelin. Their immediate destination, after a short course of one to three segments in the spinal cord, is the tract cells in the dorsal horn.

The function of the tract of Lissauer appears to be the conveyance of pain and perhaps some temperature impulses.

The Descending Tract of the Trigeminal Nerve. In the first and second cervical segments of the spinal cord a small but important tract makes its



FIG. 199.—Spino-spinal intersegmental fibers. Blue indicates the cornu-commissural bundle of Bruce. Green indicates the tract of Lissauer.

appearance in the dorsal white column. It is situated at the apex of the dorsal horn between the tract of Lissauer, which lies ventral to it, and the entrant zone of the dorsal root fibers, which lies dorsal to it. This is the *descending tract of the trigeminal nerve*. It is made up of axones which have entered the brain-stem at the level of the pons Varolii and, after bifurcation into short ascending and long descending branches, have formed a long descending bundle. This fasciculus may be traced into the upper cervical levels, and oftentimes as far downward as the fourth or fifth cervical segment. The cells of

origin for this tract lie in the *Gasserian ganglion*, which is connected with the *trigeminal nerve*. The destination of the descending trigeminal tract is the *substantia gelatinosa* of Rolando, the cells of which serve as a relay for the further conduction of sensory impulses from the head and face. In general, this tract is similar in function to the tracts of Goll and Burdach.

Summary of the Functions of the Dorsal White Column. The dorsal white column of the cord has the following functions:

1. The ipsilateral conveyance of all types of sensory impulses which have to do with general critical sensibility. Most of these impulses travel the entire length of the spinal cord from their point of entrance to the medulla oblongata before they reach their next relay station situated in the bulb.

2. The intersegmental spino-spinal association fiber which affords communication between one segment and those immediately above and below it.

3. The conduction of pain and temperature impulses for a short distance upward through the dorsal column to the dorsal horn, at which point a relay takes place and the impulses are transmitted through the lateral column of the cord contralateral to the side of the body from which the stimulus is received.

4. The conduction of all types of sensibility from certain regions of the face and head.



CONSTITUENTS OF THE LATERAL WHITE COLUMN

To facilitate description, the lateral white column may be divided into the following zones:

(1) The *juxtagriseal zone*; (2) the *circumferential zone*, and (3) the *intermediate zone*.

The juxtagriseal zone is an area of white matter of considerable thickness immediately in contact with the gray matter.

The circumferential zone begins at the tract of Lissauer and extends along the periphery of the cord as far forward as the mesial fibers of the ventral roots.

The intermediate zone constitutes the area intervening between these two zones, and is larger than either of them.

FIG. 200.—Spino-spinal intersegmental fibers. Blue indicates the location of the comma tract of Schultz.

The Juxtagriseal Zone. This zone is made up exclusively of intersegmental and intrasegmental fibers. Many of these fibers are both ascending and descending, and many of them come from tract cells situated upon the same side in the gray matter, that is, tautomeric cells. Others arise from the tract cells on the opposite side, that is, heteromeric cells. These spino-

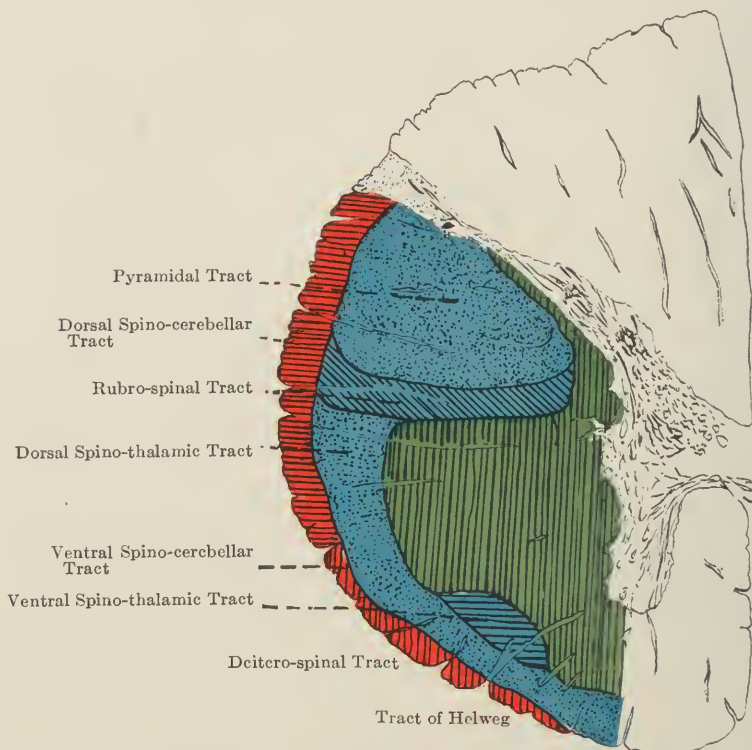


FIG. 201.—The three zones of the lateral white column. Red indicates the circumferential zone. Blue indicates the intermediate zone. Green indicates the juxtagriseal zone.

spinal ascending and descending fibers always bear the same intimate relation to the gray matter of the cord, sending their axones up or down for a distance of several segments and serving to connect the nerve-cells in the different levels with one another. In the upper cervical segments where the *formatio reticularis* is pronounced, many intersegmental fibers serve to connect the reticular formation of the spinal cord with that of the medulla oblongata.

The Circumferential Zone. This zone consists of two suprasegmental tracts and two intersegmental tracts. The suprasegmental fasciculi are both ascending tracts, namely: (1) the *dorsal spino-cerebellar tract*, and (2) the *ventral spino-cerebellar tract*. Both of the intersegmental tracts connect the medulla oblongata with the spinal cord. One of these is (3) the *Deitero-spinal tract*, which constitutes a descending or bulbo-spinal connection,

while the other is a descending tract, (4), the *fasciculus of Helweg*, which constitutes the olivo-spinal tract.

THE DORSAL SPINO-CEREBELLAR TRACT OR DIRECT CEREBELLAR TRACT OF FLECHSIG. This tract lies lateral to the pyramidal tract along the outer surface of the cord, where it occupies a somewhat narrow area. It extends

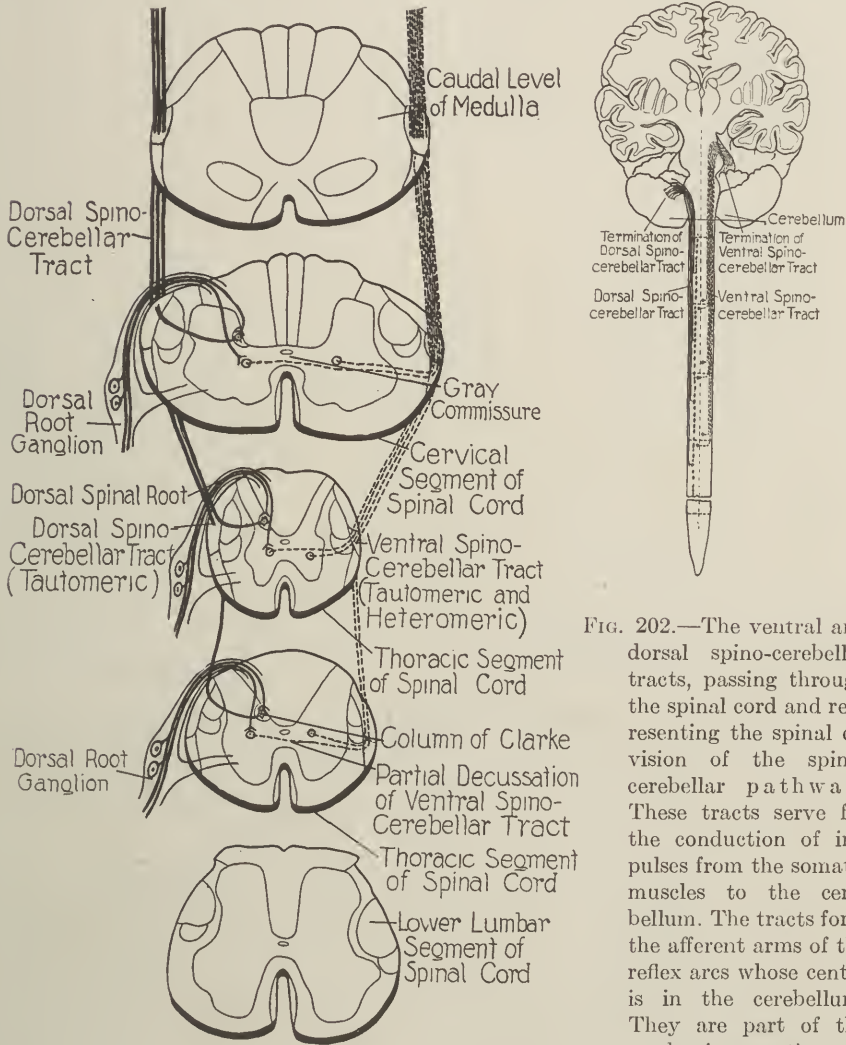


FIG. 202.—The ventral and dorsal spino-cerebellar tracts, passing through the spinal cord and representing the spinal division of the spino-cerebellar pathway. These tracts serve for the conduction of impulses from the somatic muscles to the cerebellum. The tracts form the afferent arms of the reflex arcs whose center is in the cerebellum. They are part of the mechanism active in synergic control of the muscles.

forward from the tract of Lissauer to a point midway between the dorsal and ventral root fibers. In the lower thoracic portions of the cord where the crossed pyramidal tract is coming closer to the periphery, several bundles of pyramidal fibers interpose themselves between the dorsal extremity of the tract of Flechsig and the dorsal horn.

The dorsal spino-cerebellar tract begins to appear in the twelfth thoracic segment in man. Above this level it is present in all segments of the cord. It passes into the medulla oblongata and eventually enters the inferior cerebellar peduncle, by means of which it reaches the vermis of the cerebellum.

Origin of the Dorsal Spino-Cerebellar Tract. This tract takes origin in the cells of Clarke's column, the axones of which traverse the gray matter of the same side and, entering the white matter, finally take up an ascending position as the direct cerebellar tract.

Destination and Course of the Dorsal Spino-Cerebellar Tract. The tract holds this circumferential position throughout its course in the cord. In the medulla oblongata it becomes one of the constituents of the inferior cerebellar peduncle. It has its destination in the vermis or middle lobe of the cerebellum.

Functions of the Dorsal Spino-Cerebellar Tract. The dorsal spino-cerebellar tract serves as an ipsilateral connection between the muscles of one side of the body and the cerebellum of the same side. Its function is to convey to the cerebellum impulses from the muscles, in order to furnish that organ with the stimulation adequate to the maintenance of coordination. When this connection is defective, the cerebellum is no longer properly informed as to the muscular status and it is consequently in no condition to transmit the proper impulses to the muscles which determine coordinated action.

THE VENTRAL SPINO-CEREBELLAR TRACT or the CEREBELLAR TRACT OF GOWERS. This tract lies in the circumferential zone immediately ventral to the dorsal spino-cerebellar tract. It is smaller than Flechsig's tract and less compact. It extends along the periphery of the cord as far as the ventral root fibers. It makes its first appearance in the first and second lumbar segments, being somewhat longer than the tract of Flechsig.

Origin of the Ventral Spino-Cerebellar Tract. Some of its fibers may arise in the cells of Clarke's column, and many also take origin in the body of the gray matter. It is probable that some of its axones arise from cells upon the opposite side.

Destination and Course of the Ventral Spino-Cerebellar Tract. It establishes, in the main, an ipsilateral connection between the spinal cord and the cerebellum. The tract of Gowers extends upward into the medulla oblongata and passes through the pons, occupying relatively the same position throughout its course. It terminates in the vermis of the cerebellum after traversing the outer surface of the superior cerebellar peduncle. Some of its fibers are said to pass to the cerebellum by means of the middle cerebellar peduncle and in this way to enter the opposite cerebellar hemisphere.

Intermingled with the ascending cerebellar fibers in Gowers' tract are axis-cylinders of smaller diameter which ascend to the midbrain and end in the tectum mesencephali. These fibers constitute the *spino-tectal tract*.

The function of the ventral spino-cerebellar tract is, in general, similar to that of Flechsig's tract.

THE LATERAL DEITERO-SPINAL TRACT. The most ventral of the fibers in the circumferential zone of the lateral white column constitute the lateral

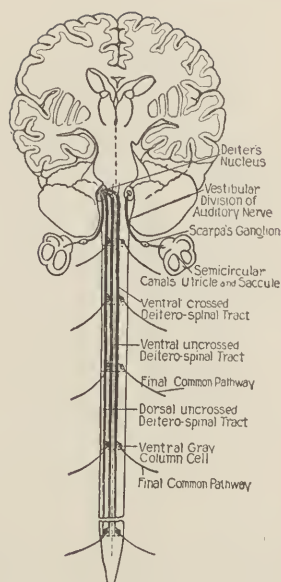
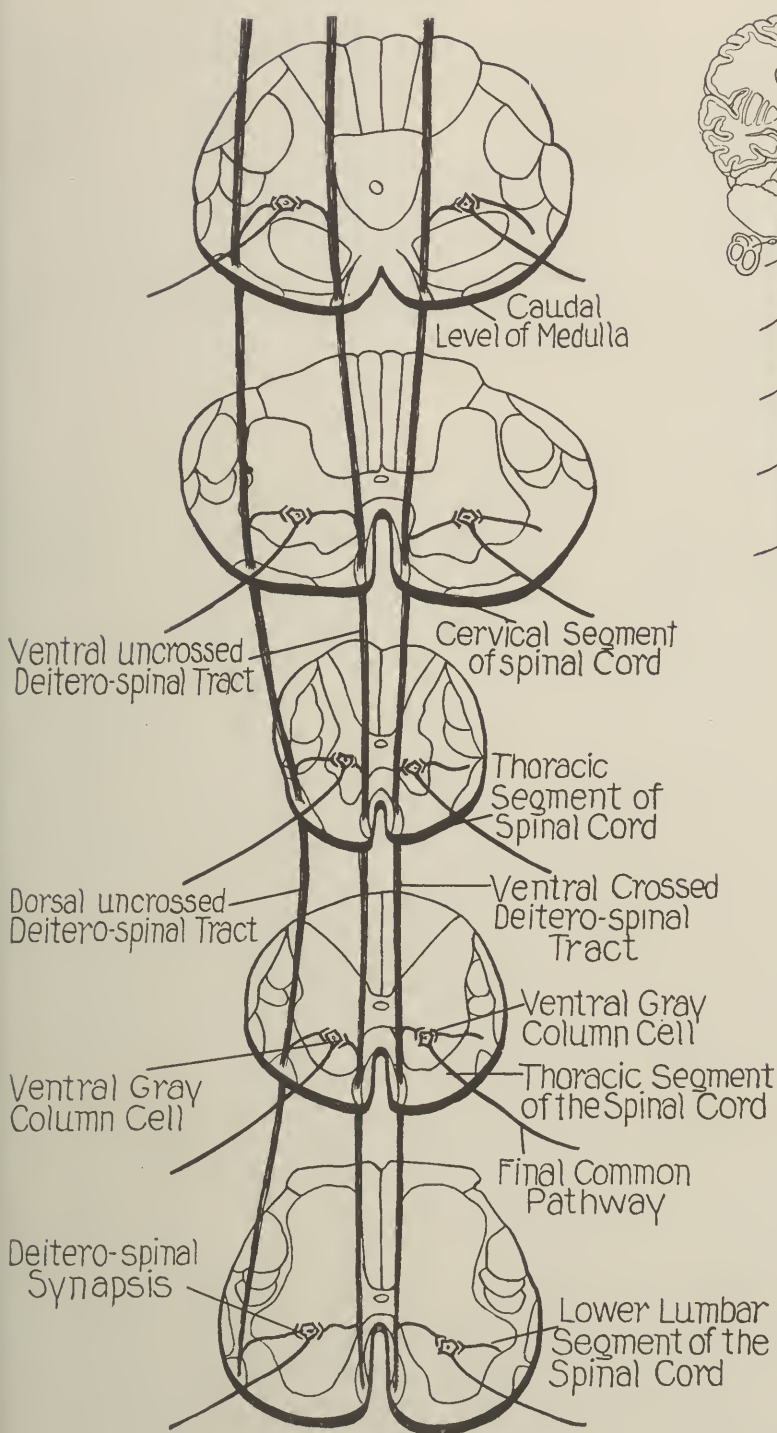


FIG. 203. — The Deitero-spinal tracts passing through the spinal cord and representing the spinal division of the vestibulo-Deitero-spinal pathway. These tracts serve to conduct the impulses necessary to equilibratory control which arise in the semicircular canals, the utricle and saccule.

Deitero-spinal tract. This bundle of fibers in cross section extends from the ventral extremity of the olivo-spinal fasciculus along the periphery of the cord as far forward as the most mesial of the ventral root fibers.

Origin of the Lateral Deitero-Spinal Tract. This tract arises in Deiters' nucleus in the medulla oblongata and descends through the entire length of the cord as far as the lower sacral segments. The lateral Deitero-spinal tract remains ipsilateral throughout its course and has its destination in the ventral column cells in all of the segments through which it passes.

Function of the Deitero-Spinal Tract. Its function is to bring the somatic muscles under the direct control of the semicircular canals in the interests of maintaining equilibrium. It is thus the direct pathway which serves to distribute the impulses of vestibulo-equilibratory control to the motor cells of the ventral gray column.

THE SPINO-OLIVARY (OLIVO-SPINAL) TRACT or TRACT OF HELWEG. This tract is a small, triangular bundle of fibers lying ventral to Gowers' tract in the circumferential zone. Its fibers are descending and connect the upper levels of the spinal cord with the *inferior olivary body* of the medulla. The origin and destination of these fibers are not definitely known and in consequence the function of Helweg's bundle is not understood.

According to some authorities, the lateral Deitero-spinal tract is comprised in the composite *anterior marginal fasciculus of Loewenthal*. Other authorities, however, maintain that the fasciculus of Loewenthal consists exclusively of descending axones from cells situated in the cerebellum. In the spinal cord the fibers of this fasciculus lie along the ventral margin of the circumferential zone and in part overlap the tract of Gowers. Whether all of the fibers in the anterior marginal fasciculus pass without interruption from the cerebellum to the cord, or whether they are all interrupted in Deiters' nucleus, is still a matter of doubt.

There is some evidence to show that the fasciculus of Loewenthal contains at least two constituent tracts: (1) A large Deitero-spinal tract establishing an uncrossed connection between Deiters' nucleus and the ventral gray column of the cord, and (2) a lesser bundle probably containing fibers from the cerebellum of the same side, *i.e.*, an ipsilateral cerebello-spinal tract.

The Intermediate Zone. This zone is composed of three principal tracts, two of which are suprasegmental: (1) The *pallio-spinal* or *lateral pyramidal tract*, (2) the *spino-thalamic tract*, in addition to which there is one intersegmental tract, (3) the *rubro-spinal tract*.

THE LATERAL PYRAMIDAL TRACT. (PALLIO-SPINAL TRACT). The lateral or crossed pyramidal tract is a large fasciculus of fibers lying in the dorsal part of the lateral column. It extends to the lowest sacral segments of the cord. In the cervical and thoracic segments it is separated from the surface of the cord by the direct cerebellar tract. In the lumbar segments, the latter tract is no longer present, and for this reason the crossed pyramidal fibers come to the surface. This fact serves as one of the distinguishing features of the lumbar and sacral cross sections of the cord. The lateral

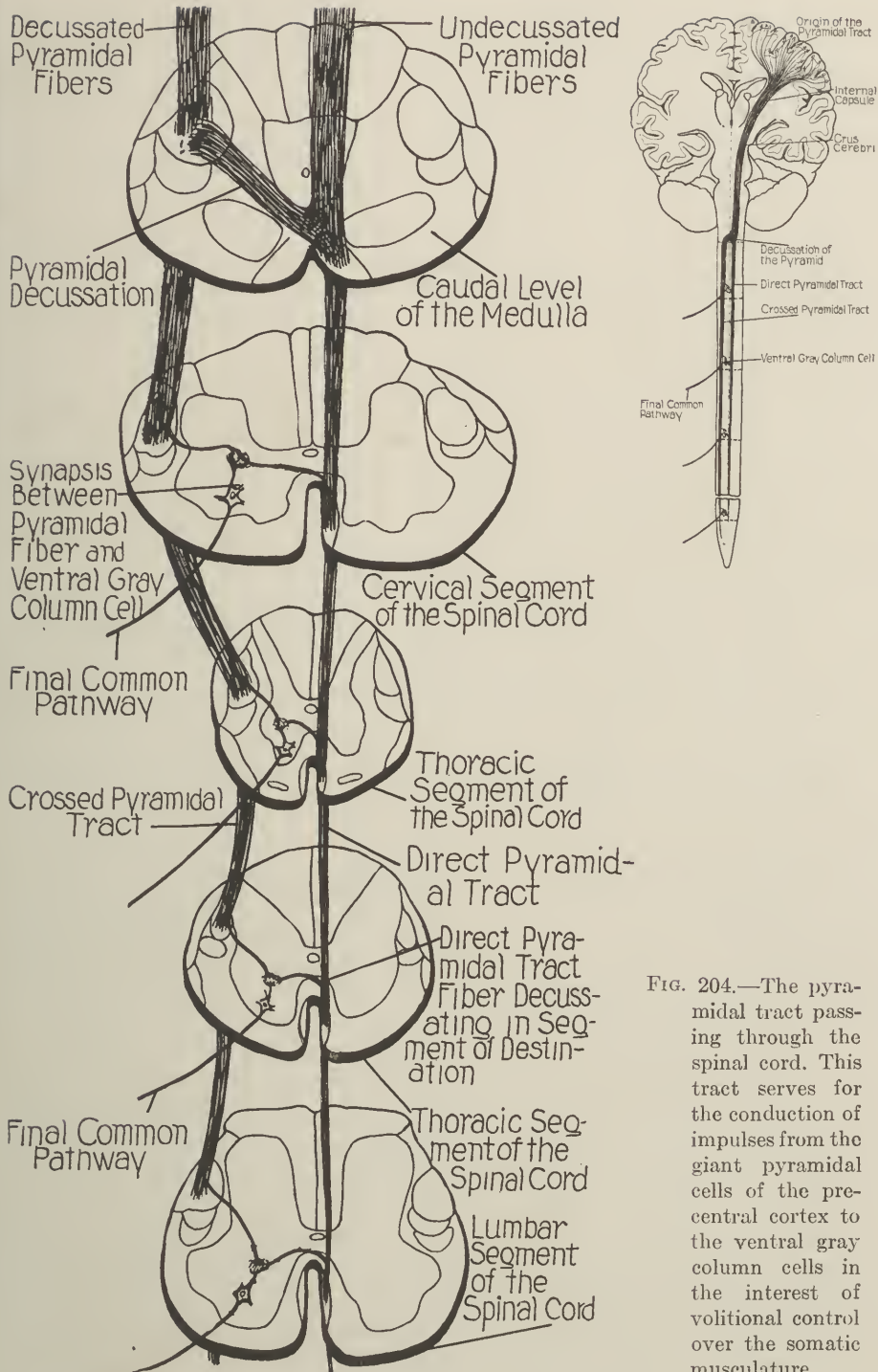


FIG. 204.—The pyramidal tract passing through the spinal cord. This tract serves for the conduction of impulses from the giant pyramidal cells of the pre-central cortex to the ventral gray column cells in the interest of volitional control over the somatic musculature.

pyramidal tract may be traced as far cranially as the medulla oblongata, where it undergoes a complete decussation with the corresponding fibers from the opposite side. It then enters into the formation of a large protuberance upon the ventral surface of the medulla, *the pyramid*. This tract is constant in all of the higher mammals and man. It is composed of seventy-five to ninety per cent of all of the pallio-spinal fibers which arise in the motor area of the cerebral cortex.

In fifteen per cent of the cases in man all the fibers arising from the motor cortex form a complete crossing in the pyramidal decussation, and no *ventral* or *direct pyramidal tract* is present. In many mammals all of the pyramidal fibers cross from one side to the other in the medulla oblongata, and the lateral pyramidal tract thus represents the total pallio-spinal connection. This is the case in the lower monkeys, although a small percentage of the pyramidal fibers do not descend in the lateral pyramidal tract in the anthropoid apes. In some mammals, especially the mouse, rat, guinea-pig, squirrel, sheep and kangaroo, the entire pyramidal tract runs downward in the dorsal white column; but in the majority of mammals, including the rabbit, cat, dog and monkey, this tract lies in the lateral column.

Origin of the Pyramidal Tract. The fibers of the pyramidal tract take their origin in the Betz cells of the motor cortex in the Rolandic area of the brain. They descend through the corona radiata, the internal capsule, the cerebral peduncle, the pons, and the uppermost portions of the medulla upon the side in which they arise.

Course, Destination and Function of the Pyramidal Tract. In the medulla oblongata the pyramidal fibers undergo a partial decussation, in which the majority of them cross from one side to the other. The crossing fibers then become collected and descend into the spinal cord as the lateral pyramidal tract. The axones of the pyramidal tract end either by direct end-arborization about the dendrites of the ventral column cells, or establish this connection through the interposition of a nuclear collection of cells known as the lateral basal nucleus in the gray matter of the spinal cord. The function of the pyramidal tract is to provide the ventral gray column cells with volitional and inhibitory control.

THE SPINO-THALAMIC TRACT. By means of this collection of fibers, a supra-segmental connection is established. The tract provides conduction toward the brain for certain impulses which come in by way of the entrant zone into the spinal cord.

Origin of the Spino-Thalamic Tract. The fibers constituting the spino-thalamic tract take origin in cells situated in the substantia gelatinosa in nearly all levels of the spinal cord. It is also probable that the fibers take origin in scattered groups situated diffusely in the dorsal gray column.

Course of the Spino-Thalamic Tract. Arising from these nerve cells, the axones ascend in the gray matter through several segments, making an oblique course in the direction of the gray commissure in which they finally cross to the opposite side. This portion of their ascent toward the brain

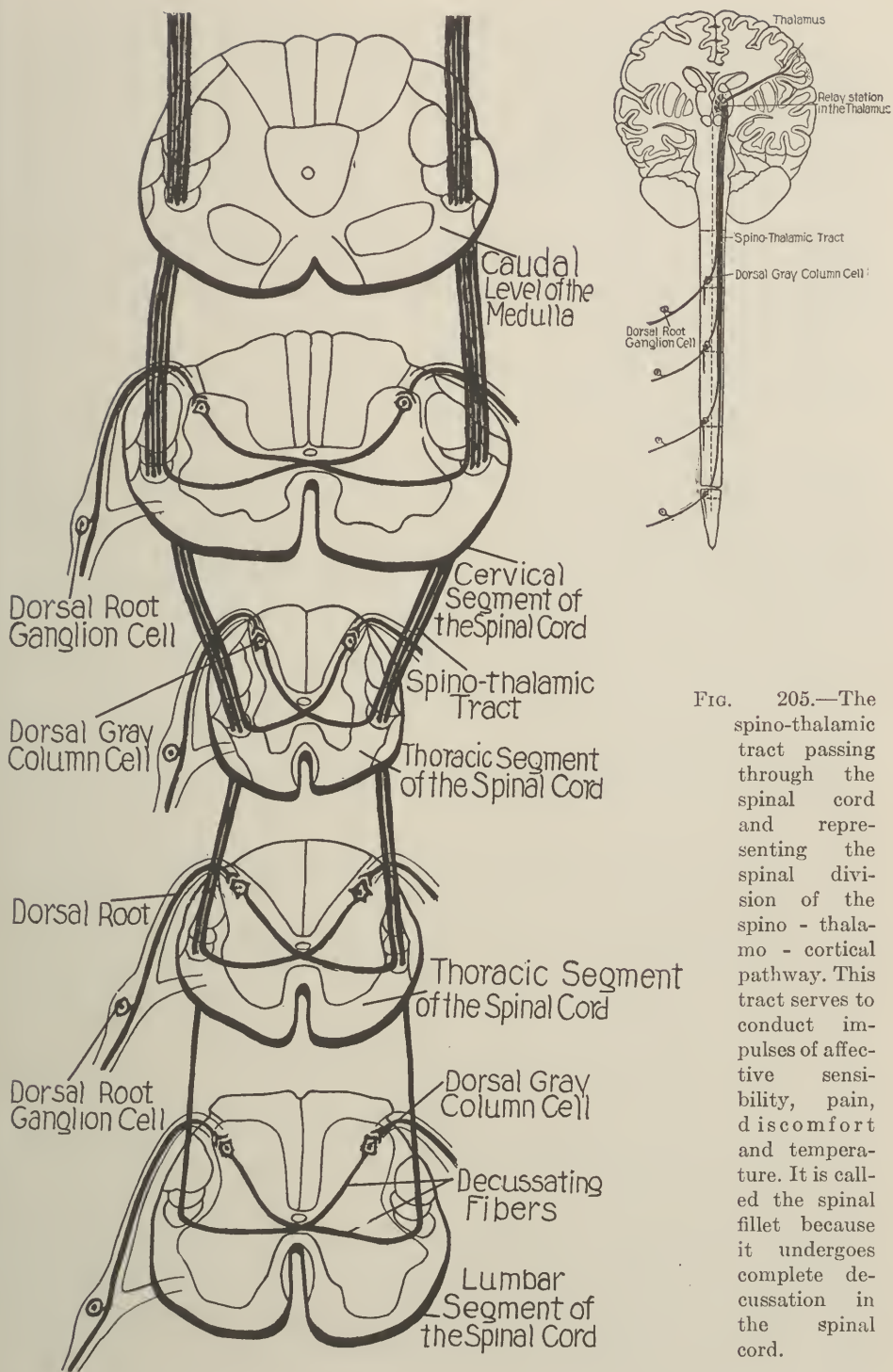


FIG. 205.—The spino-thalamic tract passing through the spinal cord and representing the spinal division of the spino - thalamo - cortical pathway. This tract serves to conduct impulses of affective sensibility, pain, discomfort and temperature. It is called the spinal fillet because it undergoes complete decussation in the spinal cord.

presents a general obliquity from below upward and inward and brings each axone into the opposite intermediate zone of the lateral white column where it turns upward to become associated with similar fibers. These fibers form the *dorsal spino-thalamic tract*. An important feature in the course of these axones is the fact that at regular intervals, usually from one to two segments above their level of origin in the spinal cord, they pass across the midline by way of the gray commissure. In so doing they meet similar fibers proceeding in the opposite direction, and form a decussation which is part of the great sensory crossing in the central nervous system. These fibers constitute the principal sensory decussation of the cord which, for this reason, is referred to as the *spinal sensory decussation*.

As the crossing fibers pass from one side to the other through the gray commissure, they lie ventral to the central canal or, where this is occluded, ventral to the remnant of that embryonic cavity.

Relations of the Spino-Thalamic Tract. The collected group of fibers which constitutes the spino-thalamic tract lies in the intermediate zone of the white matter of the lateral white column. It is situated ventral to the rubro-spinal tract, lateral to the juxtagriseal association fibers and mesial to the tract of Gowers. In the lower lumbar and sacral segments of the spinal cord this tract occupies a position ventral to both the crossed pyramidal and the rubro-spinal tracts. Upon passing into the medulla oblongata, it retains its intimate relation to the rubro-spinal tract.

Destination and Connection of the Spino-Thalamic Tract. The spino-thalamic tract connects the spinal cord with the optic thalamus. This, however, is a crossed connection due to the fact that the fibers entering into this tract cross in the cord from the side of their origin into the opposite white column. The more exact destination of the fibers in the optic thalamus will be considered in Chapter XXIII.

Function of the Spino-Thalamic Tract. This fasciculus serves to conduct impulses of pain and temperature sensibility. It will be seen that the fibers composing this tract are distinct from those which have to do with the critical qualities of sensibility, which occupy positions in the dorsal white column of the cord. For this reason it is possible that a lesion may so affect the nerve fibers in the cord as to cause a loss of pain and temperature sensibility without involving critical sensibility.

It is believed that the spino-thalamic tract serves for the conduction of all varieties of pain, both deep and superficial, and thus provides part of the pathway for the *hurt element* of somatic sensibility. Clinical evidence seems to indicate that stimuli necessary for critical as well as for affective temperature sensibility make their way to the brain in the spino-thalamic tract. It is possible, however, that these fibers may be wholly for those temperature stimuli which transcend the normal limits of temperature discrimination, and, becoming painful, serve in the capacity of producing reflexes which are part of the defence mechanism of the body. A small ventral subdivision of this fasciculus, the *ventral spino-thalamic tract*, is believed to conduct non-critical or affective tactile impulses.

THE RUBRO-SPINAL TRACT OR FASCICULUS ABERRANS OF MONAKOW. This tract is often referred to as the *extrapyramidal motor fasciculus*.

Origin of the Rubro-Spinal Tract. As its name implies, this tract is a bundle of fibers which descends into the spinal cord. The area from which its axones take origin is located in the midbrain, in a nucleus of considerable size, the *nucleus ruber* or red nucleus. The cells in this nucleus are undoubtedly of the motor type, a fact of considerable significance concerning the function of the nucleus itself.

Course of the Rubro-Spinal Tract. Leaving the cells of the red nucleus, the axones immediately cross from one side to the other, thus forming a decussation which takes place in the midbrain, the *ventral tegmental decussation of Forel*. After crossing, the fibers become collected and occupy a lateral position in the tegmentum of the brain-stem. These fibers finally enter the lateral white column in its intermediate zone and in this position descend the entire length of the cord.

Relations of the Rubro-Spinal Tract. This tract occupies a position ventral to the crossed pyramidal tracts in the lateral white column. It is situated dorsal to the spino-thalamic tract, mesial to Gowers' tract in the cervical, thoracic and upper lumbar segments, while in the lower lumbar and sacral segments, it lies in the circumferential zone. The characteristic relation of the rubro-spinal tract to the crossed pyramidal and spino-thalamic tracts is one of the most constant features in the white matter of the spinal cord. In the medulla oblongata, however, this relation is somewhat changed, due to the fact that the pyramidal fibers take up another position and part company with the other two associated fasciculi. The rubro-spinal and spino-thalamic tracts, on the other hand, maintain their constant relation, not only in the spinal cord, but also throughout the brain-stem up to the origin of the rubro-spinal bundle.

Destination and Connections of the Rubro-Spinal Tract. This tract ends in the ventral column cells of the gray matter on the side opposite its origin. This contralateral connection is accounted for by the fact that the fibers arising in the red nucleus, before they begin their descent toward the cord, immediately decussate in the ventral tegmental decussation of Forel. This decussation is complete.

In order to appreciate the significance of the connections accomplished by means of the red nucleus, the relations of this nucleus must be understood. Two principal pathways, at least, arising in the suprasegmental portions of the brain, connect with the red nucleus.

The first of these is a cerebellar connection which, by means of the superior cerebellar peduncle, affords communication between the cerebellar cortex and the red nucleus.

A second connection, and one no less important, is that determined by fibers which arise in the globus pallidus of the lenticular nucleus. By means of the ansa lenticularis these fibers make their way to the red nucleus. This determines a connection between the corpus striatum and the nucleus ruber.

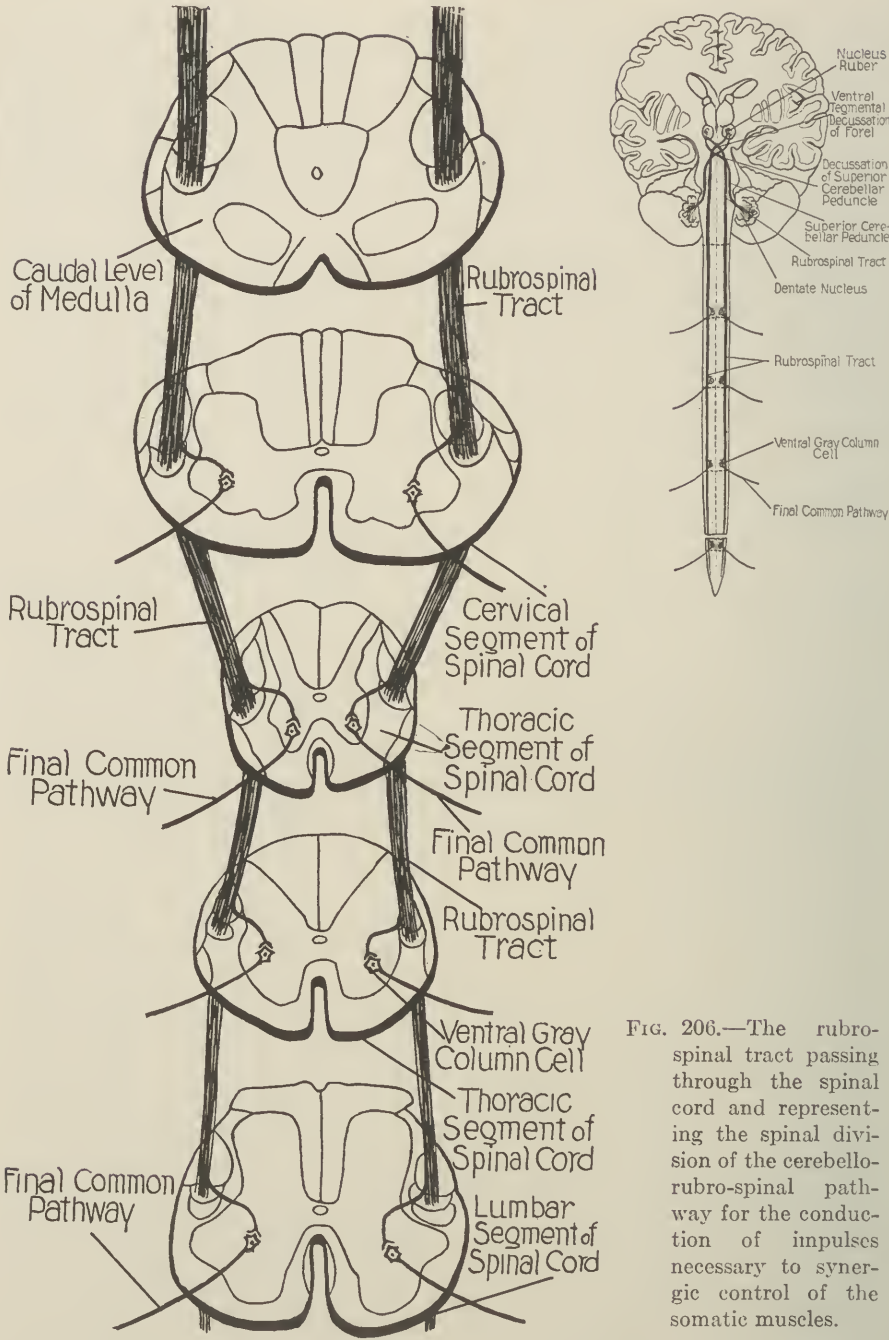


FIG. 206.—The rubrospinal tract passing through the spinal cord and representing the spinal division of the cerebello-rubro-spinal pathway for the conduction of impulses necessary to synergic control of the somatic muscles.

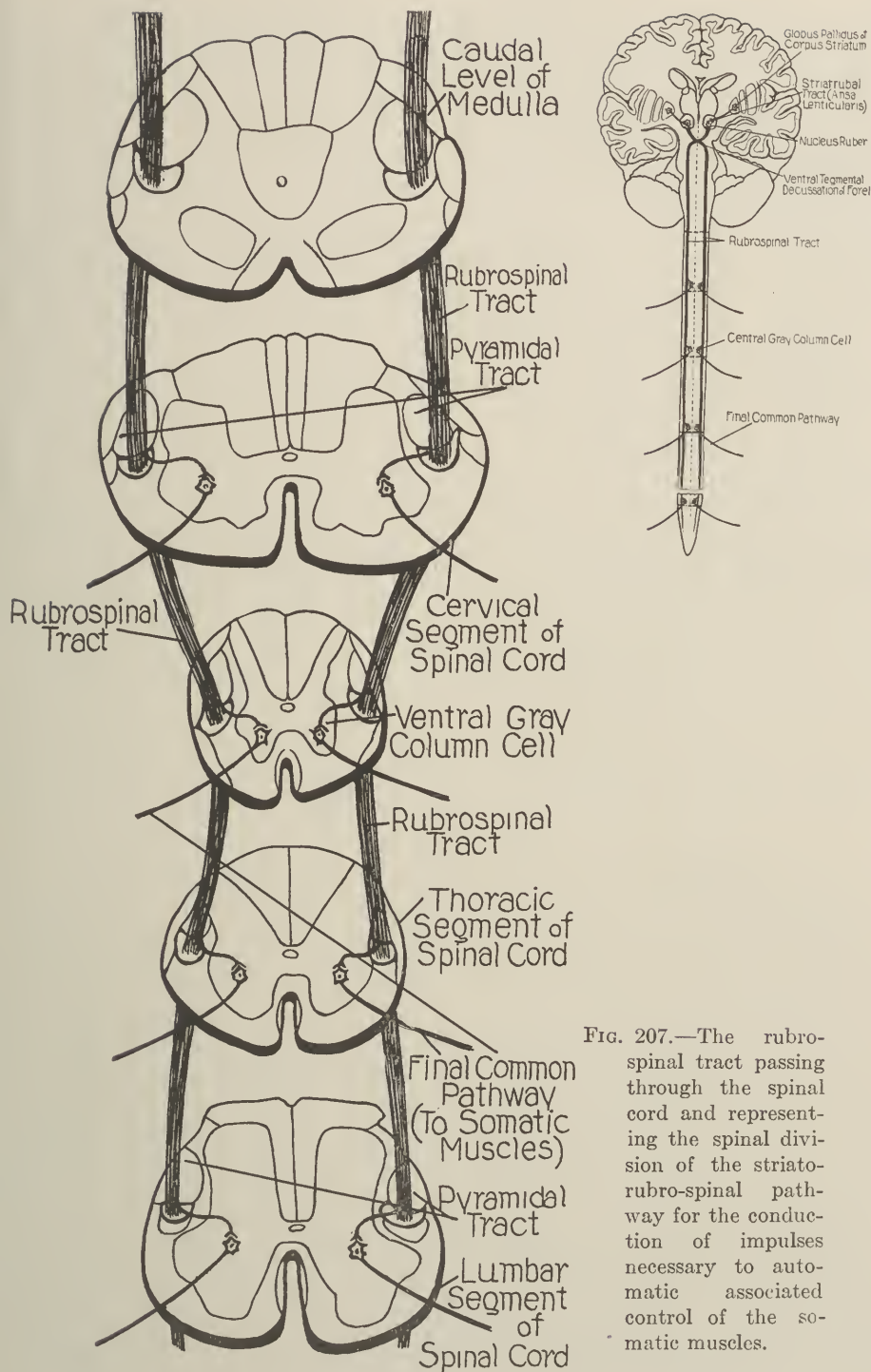


FIG. 207.—The rubrospinal tract passing through the spinal cord and representing the spinal division of the striato-rubro-spinal pathway for the conduction of impulses necessary to automatic associated control of the somatic muscles.

The red nucleus thus plays an important rôle in two pathways: (1) The cerebello-rubro-spinal pathway, and (2) the striato-rubro-spinal pathway. The connection between the corpus striatum and the spinal cord is a contralateral one; this is due to the fact that the fibers from the globus pallidus and the lenticular nucleus come directly to the red nucleus without decussation, while the fibers of the red nucleus establish a complete contralateral communication. The cerebello-rubro-spinal connection, on the other hand, is ipsilateral; this is due to the fact that the fibers in the superior cerebellar peduncle arising in the cerebellum decussate before they end in the nucleus ruber. From this point the communication between the nucleus ruber and the spinal cord is crossed. Thus, the cerebello-rubro-spinal communication presents a double crossing, first, in the superior cerebellar peduncle, and second, in the ventral tegmental decussation of Forel. In this way, one hemisphere of the cerebellum controls the corresponding side of the body, while the connection with the corpus striatum is contralateral, due to the presence of a single decussation in its pathway.

Functions of the Rubro-Spinal Tract. The function of the rubro-spinal tract is to complete a connection between the cerebellum and the spinal cord. It also acts in the same capacity for the corpus striatum. The actual spinal connection is with the ventral column cells which send their impulses to the skeletal muscles. In other words, both the cerebellum and the corpus striatum may, by the intervention of the red nucleus, act upon the final common pathway of the spinal cord and of the brain-stem. The tract introduces into the regulation of muscular activity those functional elements which are inherent in the cerebellum and the corpus striatum. The cerebello-rubro-spinal connection serves in the interests of synergic control, the details of which will be discussed at length in Chapter XXIII. The striato-rubro-spinal connection is concerned with automatic associated control, whose character and significance will be further described in the chapter dealing with the corpus striatum.

Summary of the Functions of the Lateral White Column. The following summary gives the essential facts concerning the functions which may be ascribed to the lateral white column of the cord:

1. Intersegmental connections, accomplished by means of the short axones which occupy a juxtagriseal position, serve the purposes of bringing about intersegmental association between one cord segment and another, of associating a number of cord segments, or of bringing the upper portion of the spinal cord into relation with the segments of the medulla oblongata.

2. Intersegmental connections exist between Deiters' nucleus in the medulla oblongata and the final common pathway in the spinal cord that is to say, the motor cells in the ventral gray column. This introduces the element of vestibulo-equilibratory control over the muscles of the body.

3. Afferent suprasegmental connections between the spinal cord and the cerebellum exist for the purpose of apprising that organ of the muscular

status in the interests of synergic control. This is accomplished through the tracts of Gowers and Flechsig.

4. An afferent suprasegmental connection from the spinal cord to the optic thalamus serves the purpose of conveying the sensory stimuli concerned in affective sensibility, that is, pain of all varieties and probably temperature stimuli which transcend critical limits.

5. A connection between the midbrain roof and the cord is also to be considered in the tecto-spinal tract. This may be in the interests of contributing a visuo-brachial control for movements of the arm and head to protect the eye in the event of sudden extreme illumination.

6. An efferent suprasegmental connection from the cerebellum by way of the rubro-spinal tract in the interest of synergic control.

There is another possible efferent cerebello-spinal connection in the tract of Loewenthal. This undoubtedly has the same significance as the rubro-spinal tract.

7. An efferent suprasegmental connection from the corpus striatum by way of the rubro-spinal tract serves in the interest of automatic associative control of the muscles.

8. An efferent suprasegmental connection from the motor cortex in the endbrain serves in the interest of volitional control of the muscles.

Only one of the eight principal connections in the lateral white column bears a direct relation to sensibility, *the spino-thalamic tract*. Five of the remaining tracts are related to motor regulation of the final common pathway.

The lateral white column, therefore, is preponderatingly motor, being in marked contrast to the dorsal white column, which in man is essentially sensory.

THE CONSTITUENTS OF THE VENTRAL WHITE COLUMN

This column may be subdivided into (1) a juxtagriseal zone, (2) a marginal zone, and (3) an intermediate zone. The line of demarcation between these areas is not sharp and there is some overlapping as in the case of the other columns.

The Juxtagriseal Zone. The juxtagriseal zone consists of intersegmental association fibers.

The Marginal Zone. The marginal zone or *the fasciculus marginalis anterior of Marie* comprises three principal fasciculi: (1) the fasciculus longitudinalis posterior; (2) the crossed ventral Deitero-spinal tract, and (3) the uncrossed Deitero-spinal tract.

THE FASCICULUS LONGITUDINALIS POSTERIOR. This tract takes origin in the tectum of the midbrain, probably in the *nucleus of Darkschewitsch* or the *interstitial nucleus of Cajal* in the mid-brain. Some of its fibers also arise in Deiters' nucleus. This fasciculus descends throughout the entire length of the cord in the marginal zone. It establishes connections between the midbrain and Deiters' nucleus on the one hand, and the motor cells in the ventral gray column of the cord on the other. It thus

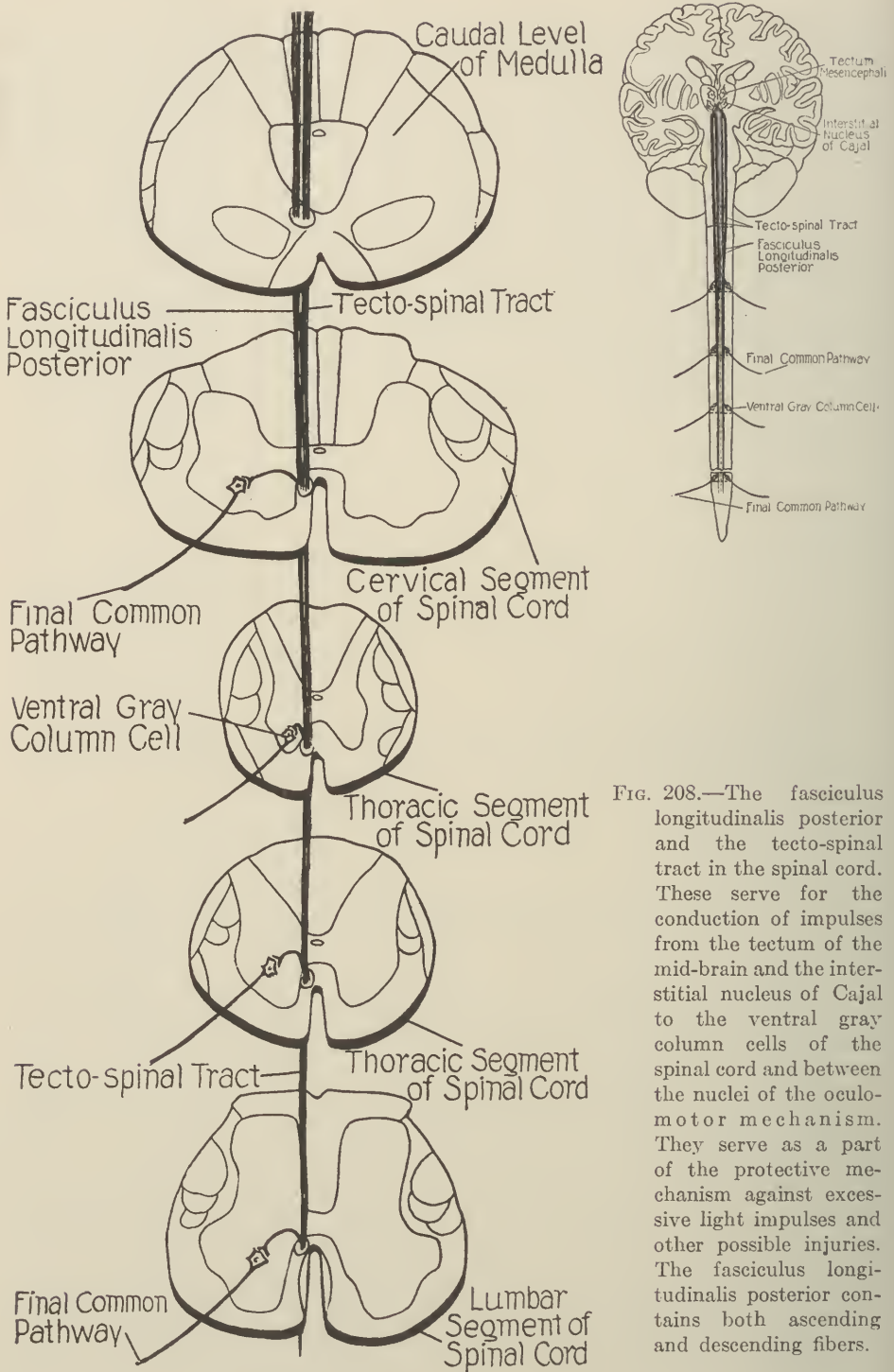


FIG. 208.—The fasciculus longitudinalis posterior and the tecto-spinal tract in the spinal cord. These serve for the conduction of impulses from the tectum of the mid-brain and the interstitial nucleus of Cajal to the ventral gray column cells of the spinal cord and between the nuclei of the oculo-motor mechanism. They serve as a part of the protective mechanism against excessive light impulses and other possible injuries. The fasciculus longitudinalis posterior contains both ascending and descending fibers.

introduces into the final common pathway elements which are concerned in the regulation of somatic motion. The Deitero-spinal connection is in the interests of vestibulo-equilibratory control, while the significance of the mesencephalo-spinal connection is not entirely clear.

The Intermediate Zone. The intermediate zone contains the uncrossed pyramidal tract or the *fasciculus of Türk*.

THE UNCROSSED PYRAMIDAL TRACT OR THE FASCICULUS OF TÜRK. This bundle is complementary to the crossed pyramidal tract and is separated from it, due to the fact that the pyramidal decussation is a partial one. The crossing involves the majority of the fibers which establish a connection between the motor cortex and the final common pathway. A certain portion of the axones, however, do not undergo decussation in the medulla and descend in their ventral position through the cord.

Origin of the Uncrossed Pyramidal Tract. The fibers of this tract arise in the Betz cells in the motor area in the endbrain.

Course of the Uncrossed Pyramidal Tract. These fibers, in association with the other pyramidal tract fibers, descend through the internal capsule into the cerebral peduncle, through the pons into the medulla oblongata. At this point they part company with the crossed pyramidal fibers. The fasciculus of Türk descends into and enters the cord in the ventral white column and continues in this position throughout its course. It decreases in size in the thoracic segments of the spinal cord and disappears in the lower lumbar segments.

Destination and Connections of the Uncrossed Pyramidal Tract. By means of the uncrossed pyramidal tract, the pallium of the endbrain in its motor area is brought into connection with the ventral gray column of the opposite side. This contralateral connection is determined by the fact that the fibers of the uncrossed pyramidal tract cross from the side in which they are descending to the opposite side through the ventral white commissure of the spinal cord. This brings the end branches of the axones into relation with the motor cells of the ventral gray column. The uncrossed pyramidal tract is analogous to the crossed pyramidal tract. It conveys the same type of impulses and furnishes a contralateral connection between the motor area in the brain and the motor cells in the spinal cord.

Summary of the Functions of the Ventral White Column of the Cord. The ventral white column of the cord serves many of the same purposes of conduction as the lateral white column. It is preponderantly motor in character. Most of its tracts are of the descending type, although there is some question as to the actual constituents in the fasciculus marginalis anterior of Marie.

1. The juxtasegmental fibers afford connections between one segment and the next or between several segments.

2. An intersegmental connection is provided by a tract arising in Deiters' nucleus and descending into the spinal cord. It serves to bring the muscles under the influence of the semicircular canals in the interest of vestibulo-equilibratory control.

3. A suprasegmental connection between the motor cortex of the end-brain and the ventral gray column cells of the opposite side is provided by the fasciculus of Türk in the interest of volitional motor control.

4. A suprasegmental connection is provided by the tecto-spinal tract which associates certain portions of the midbrain with the spinal cord. This probably is a primitive suprasegmental connection and has greater significance in the lower vertebrates than in man.

CHAPTER XII

THE SPINAL CORD

ITS PRINCIPAL SYNDROMES

It is now possible to arrive at a conception of the spinal cord as a whole, to visualize the office of this organ in regulating the activities of the body, and to appreciate the significance of the various symptom-complexes which may be produced in consequence of pathological processes affecting its several parts.

Functions of the Spinal Cord in General. The spinal cord is the immediate administrative and regulating organ controlling the somatic activities of the arms, legs, trunk and neck. It also contributes to the regulation of the visceral activities. Its chief function is the dispatch of activating impulses to the executive organs of the body—the muscular tissue and glands, in order that these structures may cooperate in an adequate expression of the animal's life. Without the spinal cord, all such expressions of life in the extremities, neck and trunk would cease.

The spinal cord brings influences to bear upon the executive organs from many parts of the nervous system. Each of these parts contributes a somewhat different yet essential influence. It is the especial office of the spinal cord to receive and blend these influences and finally to transmit them in such combinations as may be necessary for harmonious action.

The spinal cord furnishes the final common pathway for all the somatic motor impulses of the body with the exception of the head. This common pathway may itself suffer impairment or destruction as a result of disease or injury. In such case, none of the somatic motor impulses is delivered to its respective effectors.

The final common pathway may be cut off from one or more of the sources from which it receives important regulating influence. In such a case, somatic motor activities would manifest one or more pathological defects.

The Isomeric and Allomeric Functions of the Cord Segment. In addition to furnishing the final common pathway for all somatic motor activities, the spinal cord acts as a series of governing segments controlling the several segments of the body. Each body segment may be likened to a principality or state whose government is vested in a centrally placed capital, the spinal cord segment. Although the segmental character of the body may be recognized in many invertebrates, its distinctness in the vertebrates has been largely obscured by segmental fusions in response to the need of more intimate cooperation of the body segments in the purposes of life. In this way, the independence of segmental individuality has seemingly been sacrificed in the interests of greater efficiency through mutual segmental

cooperation, yet the fundamental segmentation of the body and spinal cord, to whatever extent obscured, still remains a potent fact. Upon its recognition depends a proper understanding of the diseases of the spinal cord. If, for example, a particular segment of the cord is diseased, this disorder will immediately reflect itself in grave disturbances of the muscles, glands, skin, bone and blood vessels in the corresponding body segment.

But the spinal cord is something more than the capital of a single state. As a seat of government, it is coordinated with many others like it, so integrated as to control the federation of body segments which constitute the animal. The close community of interests between the body segments demands the closest possible means of communication between the spinal segments. For this reason the destruction of a single cord segment—as when pierced by a bullet—not only affects the corresponding body segment, but produces disturbances in the structures controlled by neighboring and remote cord segments.

Regarded as a whole, therefore, the spinal cord segment appears to be endowed with a dual responsibility to the body: First, its responsibility to the immediate body segment which it governs, and which for this reason may be called its *isomeric function*. Second, its responsibility to many other body segments, which may be termed its *allomeric function*.

Clinical Differences in Lesions of the Gray and White Matter. The isomeric function of the segment depends chiefly upon its gray or active substance, while its allomeric function depends upon the white or conducting substance. When disease destroys the gray matter of a segment, it is the isomeric functions which suffer, and the patient presents a condition quite different from that caused by disease in the white matter.

Diseases of the gray matter, in the main, manifest themselves as disturbances in the *specific segmental control* of the body, that is, disorders in the influences which the individual cord segments supply.

Diseases of the white matter manifest themselves mainly as disturbances in the *integrative suprasegmental control* of the body, that is, disorders in the influences dependent upon the cerebrum and cerebellum.

This fact is well illustrated in the case of a lesion destroying the gray matter of the 8th cervical segment, as a result of which the symptoms are confined to the structures in the hands and forearms. The character of the symptoms is determined by the defects in the specific segmental functions of the gray matter.

In contrast to this is the much more extensive disturbance resulting from the destruction of the white matter of the 8th cervical segment, leaving intact the gray substance. In this case, the symptoms will be manifest in somatic structures at and below the level of the lesion, that is, in the hands and forearms, trunk and legs. These symptoms take their character from the defects produced in the integrative suprasegmental control of the body, and represent the loss of cerebral control over the spinal cord.

The specific segmental functions of the gray matter have previously been discussed. When diseased or injured, the gray matter will be defec-

tive in some or all of its functional activities. Thus it may become deficient in the specific function of its ventral gray column. Under such conditions the idiodynamic, reflex, myotonic and volitional control will present pathological changes, or it may be deficient in the specific function of its lateral gray column, in which event vasomotor and visceral disturbances appear. Usually, however, the ventral and lateral gray columns are simultaneously affected.

The dorsal gray columns and dorsal root ganglia may become defective in their specific functions, and the symptoms will then confine themselves largely to sensory disturbances. Pathological changes in the gray commissure also bring about specific disturbances in the form of sensory changes.

The integrative suprasegmental functions of the white matter have already been given in detail. When diseased or injured, the white matter may be rendered defective in some part or all of its functional activities.

Pathological changes may involve the dorsal white column, and in this case the symptoms will be those due to defects in the conduction pathway designed for the conveyance of critical sensibility.

The lateral white column may be diseased or injured, under which conditions the symptoms produced would be those due to the interruption of the cerebral influence contributing volitional control to the movements of the body. A lesion in this portion of the white matter may also interrupt the pathway conveying the affective elements of sensibility, mainly, the hurt element and temperature sense, resulting in a definite group of sensory disturbances.

Lesions in the ventral white column are not only less frequent than those affecting the lateral and dorsal columns, but are also less definite in their symptoms. When present, however, their essential and demonstrable defect is made apparent in disturbances of volitional control.

It is a general rule that pathological processes seldom involve simultaneously all the elements of the gray matter in the spinal cord. Infectious agents, toxic substances, and even degenerative processes seem to have a selective affinity for one or another part of the gray matter, and thus it is possible to recognize symptom-complexes or syndromes attributable to disease in the ventral gray matter, in the dorsal gray matter or in the gray commissure.

Similarly, pathological processes have selective affinity in the white substance, in consequence of which there are syndromes due to involvement of the dorsal white column, of the lateral white column, and some, more vaguely defined, due to involvement of the ventral white column.

Clinical Syndromes as a Means of Interpreting Spinal Cord Function.

One of the most effective methods in the investigation of the functions of the spinal cord is the correlation of clinical symptoms with the pathologic processes which produce the well recognized spinal cord syndromes. These syndromes may be classified in three groups:

1. Syndromes of the gray matter.
2. Syndromes of the white matter.

3. Syndromes of the gray and white matter combined.

They are to be regarded as translations of the physiological reactions of the spinal cord into the clinical terms of disturbed function. Only such spinal cord diseases as most directly serve to elucidate the physiology of the several parts are here considered.

Every discrete lesion in the cord is indicated clinically by two sets of clinical evidence: First, evidence of disturbed function, revealed by pathological signs and symptoms which *locate the focus of the pathological process*. Second, evidence of undisturbed function revealed by normal reactions which are indicative of the normal tissue surrounding the focus of the pathological process. This *establishes the definite boundaries which circumscribe the lesion*. These two sets of facts are necessary in the delineation of each spinal syndrome.

SYNDROMES OF THE GRAY MATTER

The syndromes of the gray matter of the spinal cord may be classified in three groups:

- I. Syndrome of the ventral gray matter.
- II. Syndrome of the dorsal gray matter.
- III. Syndrome of the gray commissure.

The most significant signs and symptoms are those which indicate the focus of the lesion. They should be considered first and followed by the evidence which identifies the boundary of the lesion.

Syndrome of the Ventral Gray Matter. HISTORY. A child, four years of age, having a good family history and without previous illness, on June 14, 1916, began to complain of slight headache and fatigue toward the end of the day. Upon putting the child to bed the mother, believing that the body was warmer than usual, took the temperature by rectum, and found it to be 101.2°. The child passed a restless night, tossing and moaning in his sleep. Toward morning he became quieter and slept so profoundly that the mother became alarmed. She finally aroused the baby and soon observed that there was something wrong with the right arm. Upon watching the child, it became evident that he could not move his arm, forearm or hand, and the entire limb hung limply at his side when he sat up or stood up in bed to be dressed. No persuasion could prevail upon him to make any movement with the right hand or fingers, forearm, arm or shoulder. The temperature taken at this time was normal. The child's appetite was good and he made no complaint of headache, fatigue or malaise. He was mentally alert and showed a disposition to be playful as was his usual habit. The attending physician upon seeing the child recognized the condition at once as similar in all its principal details to the case of a little girl whom he had seen the previous day in the house adjoining that of the patient's family. The fact that another child was similarly affected next door was suggestive of an actual epidemic or epidemic tendency.

EXAMINATION. Upon examination made so that all four components of the nervous system were carefully scrutinized, the following facts were brought to light:

(a) *Status of the Somatic Motor Component.* Testing voluntary movement and strength of the muscles of the left arm and in both legs as well as in the trunk and neck, it was found that all of this musculature was normal. The child had no volitional control over the right arm, nor did he make a movement of any kind with this part of the body when requested to do so. In other words, there was a complete voluntary paralysis of the right upper extremity.

In addition to the absence of voluntary control in the right arm, there was a complete lack of synergic and automatic associated control.

The tone of all of the muscles about the right shoulder, elbow, wrist and hand was greatly reduced, while normal tone was retained in all other muscle groups of the body.

The reflexes, including the pectoral, triceps, biceps, olecranon, radial, ulnar and wrist reflexes, were all absent in the right arm; elsewhere in the body both deep and superficial reflexes were normal. The absence of tone and reflex control in the right arm occasioned such a lack of muscular resistance that the entire arm could be swung like a flail. If elevated and dropped, it would fall and swing much as does the arm in the articulated skeleton.

At the end of several weeks, the right arm showed a marked wasting in all of its muscle groups, including the hand, forearm, arm and shoulder girdle. At this time, also, a marked loss in the normal contour of the muscle bellies was observed, and upon testing the nerves and muscles with electricity, it was found that all response to the faradic current was abolished and that the anode closing contracture was much stronger than the cathode closing contracture, indicating the presence of the *reaction of degeneration* (R. D.).

(b) *Status of the Splanchnic Motor Component.* During the first few days, there was little evidence of involvement of the vasomotor system; at the end of two weeks, however, the arm began to assume a mottled appearance due to the congestion of blood in the cutaneous capillaries and venules. Furthermore, upon examination, it was found that the surface temperature of the right arm was two degrees lower than that of the left arm, of the trunk or the legs. The rest of the body showed no such change.

(c) *Status of the Somatic Sensory Component.* The child at no time complained of any subjective change in sensibility. He had no numbness, tingling, burning or any other form of dysesthesia, nor did he complain of pain. He was not at any time especially conscious of the difficulty in his arm, and although unable voluntarily to control the movements of the right arm, he did not seem particularly annoyed or inconvenienced by this defect. Objectively, upon examination, all qualities and modalities of somatic sensibility were found to be intact.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of any sensory disturbance due to disorder of the splanchnic sensory component.

INTERPRETATION AND ANATOMICAL ANALYSIS. The headache, temperature and restlessness of short duration indicated the occurrence of an acute infection which rapidly ran its course. The complete paralysis of the right arm, so suddenly produced, showed the profound effect of the disease.

The main lesion was somewhere in the nervous system, and there was complete evidence of its focus. This was afforded by the fact that the final common pathway was completely blocked. The total paralysis of the right arm showing the loss of volitional control and strength of the muscles, while all the other muscles of the body remained normal, both in strength and volitional control, the loss of synergic and automatic associated control, the marked loss of muscle tone, the absence of the deep reflexes in the right

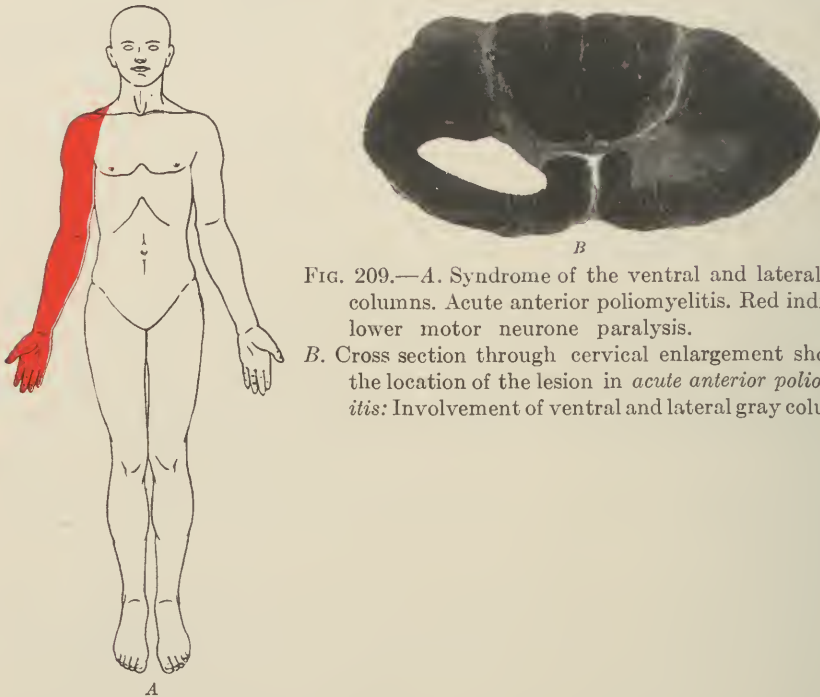


FIG. 209.—A. Syndrome of the ventral and lateral gray columns. Acute anterior poliomyelitis. Red indicates lower motor neurone paralysis.

B. Cross section through cervical enlargement showing the location of the lesion in *acute anterior poliomyelitis*: Involvement of ventral and lateral gray columns.

arm and the ultimate loss in volume and contour of the muscles, together with the presence of the reaction of degeneration, indicated a lesion in the final common pathway of the *somatic motor system* controlling the right arm. Furthermore, the reduction of surface temperature in the right arm as compared with the rest of the body, and the venous congestion indicating a loss of vasomotor tone, pointed to a disturbance in the final common pathway of the *splanchnic motor system*.

The involvement of these two final common pathways points to a lesion in one of two places, *i.e.*, either in the ventral and lateral gray columns or in the peripheral nerves leading therefrom.

The evidence of circumscription of the lesion shows that it cannot be in the peripheral nerves, for the reason that were an acute infective process

to involve these structures, some degree of sensory disturbance would in all probability be present. But the total absence of dysesthesia, paresthesia, pain and objective sensory disorders, suffices to rule out the possibility of a lesion in the peripheral nerves. This evidence of circumscription also draws the boundaries of the lesion by showing that the pathways for all types of sensibility are intact in the spinal cord and that the pathways for suprasegmental motor control are still effective. The boundary line thus drawn limits the lesion to the ventral and lateral gray columns of the right side of the cervical enlargement of the spinal cord.

DIAGNOSIS AND PATHOLOGY. The diagnosis of the condition is *acute anterior poliomyelitis*. The pathology of this lesion is an acute inflammatory reaction involving the neural elements in the ventral and lateral gray columns in such a way as either to destroy or gravely impair the large motor cells which serve as the neurosomata of the final common pathway. This disease has the tendency to occur in extensive epidemics.

NOMENCLATURE. *Acute anterior poliomyelitis* is also known by several other terms. It is sometimes spoken of as *infantile flaccid paralysis*, *infantile spinal paralysis*, "*polio*," *epidemic spinal paralysis*, and the *Heine-Medin disease*.

VARIATIONS. *Acute anterior poliomyelitis* varies greatly in its mode of onset as well as in its course and duration. In most cases, the initial paralysis represents the maximum of involvement and is followed by greater or less recession, leaving a residual permanent paralysis. In other cases the paralysis is progressive, or there may be a recession of the initial paralytic symptoms so marked as to result in an almost complete recovery of the patient. The most common form of the paralysis is found in one upper extremity. Often the arm and leg upon the same side are affected, giving the appearance of a flaccid hemiplegia. One leg alone may be involved, or only a portion of the leg, more especially the muscle group below the knee, and in particular the anterior tibial or peroneal groups; frequently both legs are involved with equal severity, and in rarer cases the musculature of the entire body, including the extremities, trunk and neck, presents a profound degree of paralysis.

SUMMARY. The essential clinical features of acute anterior poliomyelitis are:

(1) Loss of idiodynamic, reflex, tonic and volitional control in the spinal cord segments involved by the inflammation, resulting in the following changes in the corresponding muscles:

(a) Atrophy with loss of contour and the presence of the reaction of degeneration.

(b) Loss of the deep and superficial reflexes.

(c) Marked loss of muscle tone.

(d) Paralysis due to interruption of the final common pathway, which blocks the transmission of volitional impulses; a *flaccid paralysis*.

(2) Vasomotor paralysis, as shown by the mottling of the skin and the reduced surface temperature of the affected parts.

(3) Restriction of the somatic and splanchnic motor symptoms to the area corresponding to the spinal cord segment involved.

(4) Absence of sensory disturbances.

Syndrome of the Dorsal Root Ganglion: Dorsal Root Ganglion. HISTORY. A young woman, thirty-two years of age, began to complain of pain between the shoulders, along the back of the left arm, and on the left side of the chest. She felt slightly indisposed, had some fever and headache with loss of appetite lasting for several days. During the second night of her illness, she was awakened by more severe and burning pain in the areas already mentioned. In the morning it was found that she had a

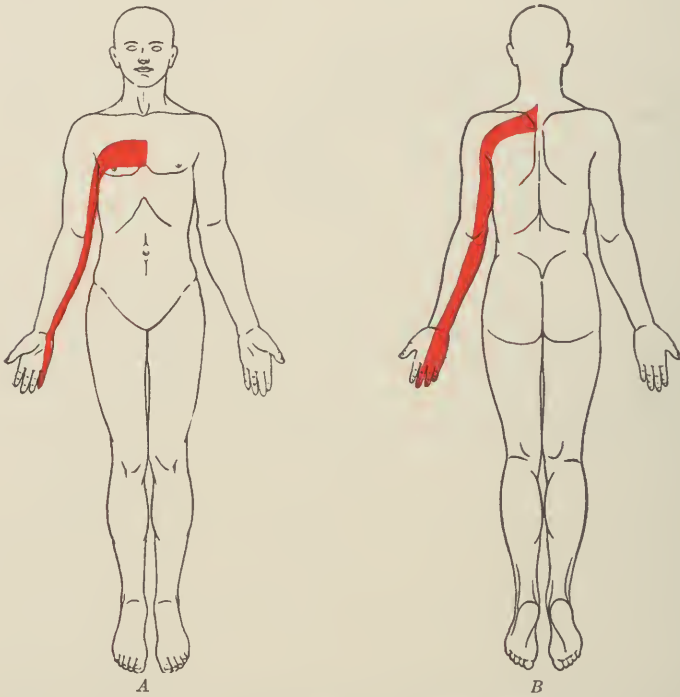


FIG. 210.—A and B. Syndrome of the dorsal root ganglion; Acute posterior poliomyelitis: (Herpes Zoster). Red indicates area of pain, hypalgesia and hypesthesia.

series of small blisters extending from the mid-dorsal line on the left side around the chest to the mid-ventral line. This zone of blisters, or *herpetic zone*, was sharply limited above and below. In addition to that upon the chest, there was a considerable area extending from the left axilla down the back of the left arm almost to the elbow. The blisters were extremely sensitive to touch. When seen by her physician, her general systemic condition was much improved, the fever had disappeared and she soon regained her appetite. The herpes, however, persisted for several weeks. Although the pain subsided to a considerable degree, it was gradually replaced by an itching sensation, and finally by numbness.

EXAMINATION. (a) *Status of the Somatic Sensory Component.* Subjectively the patient complained of pain, followed by itching and subsequently by a feeling of numbness, the entire sensory disturbance lasting the greater part of a month. The pain combined a superficial burning sensation with a deep and steady ache. When first examined, the area covered by the blisters was extremely sensitive in all types of sensibility. Paresthesia was particularly apparent; the application of the pin-point produced a burning sensation; stroking with a camel's hair brush caused a sensation of pain. In the area of these changes, there was marked hyperesthesia, hyperalgesia and hyperthermesthesia. The distribution of the herpes, as well as the sensory disorders, is of much importance. It was found upon testing that the area upon the body thus affected was limited to the 8th cervical, 1st, 2d, and 3d thoracic dermatomes, the anterior and posterior dermatomic divisions being equally involved.

(b) *Status of the Splanchnic Motor Component.* A profound disorder in the vasomotor control of the herpetic zone was evidenced by the appearance of the blisters upon the skin, all of which were confined to the dermatomic regions already enumerated as presenting disturbances of sensibility.

(c) *Status of the Somatic Motor Component.* The volitional control and strength of all the muscles, the equilibratory, synergic and automatic associated control, myotonic, reflex and idiodynamic control, were normal in all the muscles underlying the area of the herpetic involvement. This was also true of all other muscles of the body.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of any change in the elements of visceral sensibility.

INTERPRETATION AND ANATOMICAL ANALYSIS. The malaise, fever, headache and anorexia indicate an acute infection.

The chief evidence of the focus of the lesion shows the disturbance to have been in the somatic sensory component with some involvement of the splanchnic motor component, while the lesion itself was irritative in nature. The distribution of the cutaneous lesions showed that the pathological process was a disturbance of segmental function limited to dermatomic areas of the left side and supplied by the 8th cervical and 1st, 2d and 3d thoracic segments, involving alike the anterior and posterior dermatomic divisions. This localization provides two alternatives: First, in the peripheral nerves, including the 8th cervical, 1st, 2d and 3d thoracics, or, second, in the dorsal root ganglia corresponding to these nerves. As a rule, peripheral nerve lesions give sensory changes confined to the anterior dermatomic divisions; here both anterior and posterior dermatomic divisions were implicated, which is the case in dorsal root ganglion involvement as well as in dorsal root lesion.

The evidence of circumscription of the lesion afforded by the normal status of somatic motor component indicates an intact condition of the ventral gray column and the ventral and lateral white columns. The normal status of the somatic sensory and splanchnic sensory components, except in the cervical 8th, and 1st, 2d and 3d thoracic dermatomes upon the left

side, limits the lesion to the dorsal root ganglia of the 8th cervical, and 1st, 2d and 3d thoracic cord segments upon the left side.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is an *inflammation of the dorsal root ganglia*. The pathology is an acute inflammatory reaction due in all probability to an infection producing an irritative disturbance in the ganglia involved. This irritation is often followed by degeneration, thus explaining the original irritability in the cutaneous areas followed by a general reduction in all types of surface sensibility.

NOMENCLATURE. This disease is known as *acute posterior poliomyelitis*, *herpes zoster* and *shingles*.

VARIATIONS. Pain is a constant symptom in this disease. The herpetic eruption may be a scanty or a profuse crop of blisters. The distribution of both pain and the herpetic zone depends upon the dorsal root ganglia which are involved in the inflammatory process. This is most common about the trunk, but may occur upon the face, the neck, the arms and the lower extremities.

SUMMARY. The essential clinical features of acute posterior poliomyelitis are:

- (1) The sudden appearance of localized pain in regions limited to one or more dermatomes, and always including the anterior and posterior dermatomic divisions. This pain is accompanied by acute objective irritability, which, however, is subsequently replaced by some diminution in all types of somatic sensation.

- (2) The coincidence in the dermatomic regions of the pain of a crop of small blisters, each of which is extremely sensitive to touch and pressure.

- (3) The absence of all evidence of motor disturbance, with the possible exception of a slight increase in the reflexes in the affected area, and intact somesthetic sensibility with the exception of the dermatomes involved in the lesion.

Syndrome of the Central Gray Matter: The Gray Commissure.

HISTORY. A young man, twenty-two years of age, observed that he frequently burned the tips of his fingers of both hands when lighting a cigarette. He was unable to understand, however, why it was that even though the lighted match or the lighted end of the cigarette came in actual contact with his skin, he experienced no feeling of pain. In the course of the next few months, he observed that he had lost his usual sensibility of pain in the tips of the fingers, as well as in the hands and forearms, although in these latter areas the diminution in sensory acuity was less marked than in the fingers. He also observed that he could put his hands in extremely hot water without experiencing any discomfort. Several ulcers developed on the tips of his fingers, probably in areas which he had burned with his cigarettes. The patient could not understand why these ulcers were so long in healing, but explained the fact to himself on the ground that he had probably injured the ulcerated areas from time to time in consequence of his lack of feeling in the fingers.

EXAMINATION. (a) *Status of the Somatic Sensory Component.* Subjectively, the patient complained of little; he was not conscious of any tingling, any numbness or burning in his hands. What had impressed itself

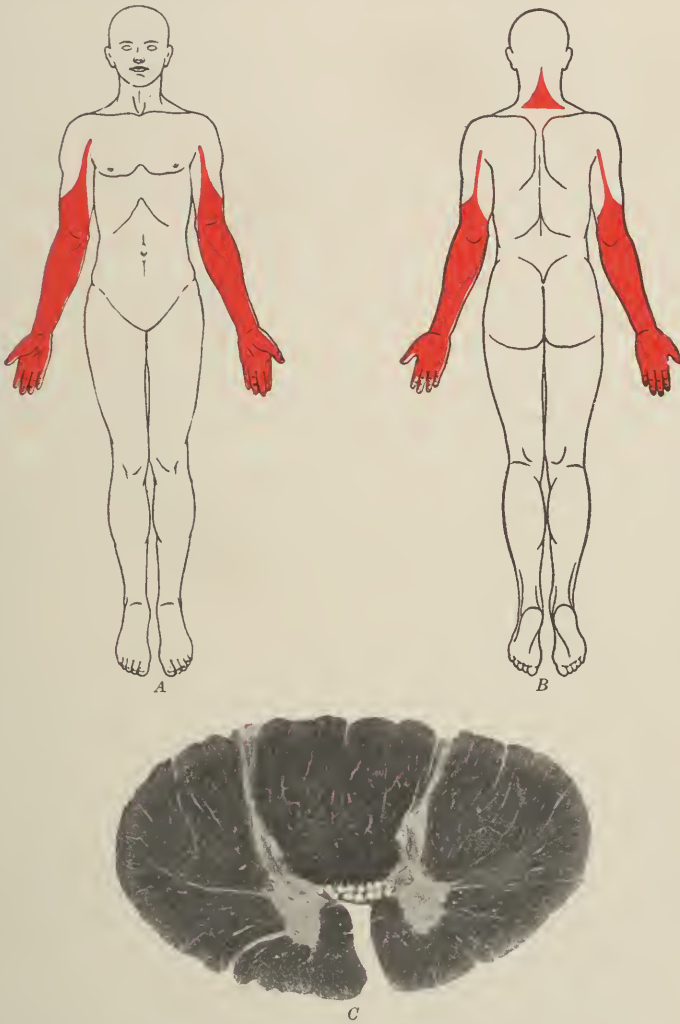


FIG. 211.—A and B. Syndrome of the central gray matter—the gray commissure. Syringomyelia. Red indicates analgesia and thermanesthesia with retention of discriminative sensibility. Syringomyelic sensory dissociation.

C. Cross section through first thoracic segment showing the location of the lesion in *Syringomyelia*: Involvement of the gray commissure.

upon him, was the fact that things which formerly hurt him no longer did so, and he seemed to have lost perception of hot and cold.

Objectively these observations were borne out by tests. The application of hot and cold test tubes to the skin over the fingers, hands and forearms uniformly brought the wrong response, as the patient was unable to dis-

tinguish the temperature of the object applied, even though the tubes were filled with water as hot as 44° centigrade, or of as low a temperature as 10° or 15°. He could not distinguish the difference between a hot test tube and a piece of ice rubbed over the tips of the fingers. Tested with a pin-point over the fingers, hands and forearms, the same general lack of sensibility was noted. The patient was unable to define the character of the contact, and usually described the pin-point as a sense of touch or pressure. Over-extension of the fingers or forced flexion of the phalanges did not occasion pain or discomfort. Similar tests made upon the toes at once brought a protest from the patient when the degree of extension or flexion passed beyond the limits of usual extension or flexion in these joints.

In marked contrast to these disturbances in temperature sensibility and in the hurt element of sensation, was the fact that the lightest touch, the recognition of two points (Weber's circles), the tuning fork, and deep as well as light pressure, presented normal sensibility. Furthermore, somesthetic sensibility was normal in all parts of the body except the fingers, hands and forearms. The sensory examination, therefore, revealed the fact that the patient was suffering from a striking type of *sensory dissociation*.

(b) *Status of the Somatic Motor Component.* At the time of this examination, volitional control in the muscles and muscle strength, equilibratory, coordinative, automatic associated control, myotonic, reflex and idiodynamic control, were all normal.

(c) *Status of the Splanchnic Motor Component.* At the first examination there was nothing of pathological moment.

(d) *Status of the Splanchnic Sensory Component.* There was nothing indicating pathological change in this division of the nervous system.

INTERPRETATION AND ANATOMICAL ANALYSIS. The history of this case indicates a chronic and progressive lesion.

The evidence of the focus of the lesion clearly shows that the somatic sensory component had been involved by a progressively destructive lesion. The distribution of the lesion and its limitation to the dermatomes supplied by the 6th, 7th and 8th cervical and 1st thoracic segments of the spinal cord indicate a spinal lesion in or near the segments already enumerated.

The evidence of circumscription of the lesion, on account of the marked sensory dissociation, shows that the pathological process is in the spinal cord segments rather than in the peripheral nerves, the dorsal root ganglia or the dorsal roots themselves. The disturbance could not be in the dorsal gray column, because this part of the nervous system probably serves as a relay for all types of sensibility; neither is the disturbance in the ventral gray column, since there are no motor symptoms; nor is there any evidence of involvement of the dorsal, lateral or ventral white columns. For these reasons, the disturbance must be in the central gray matter, in which there occurs a complete crossing of the fibers designed to convey to the brain sensory stimuli concerned with the temperature sensibility, and also carrying

the hurt element of sensation. A lesion in this position would interrupt the pathway for pain and temperature and thus produce the peculiar type of sensory dissociation which marks this disease, *syringomyelic sensory dissociation*.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is *syringomyelia*, (*syrinx*, tube; *myelon*, cord). The lesion which causes this disturbance is a destructive one, beginning usually as an increase in the cells in the central gray matter which subsequently break down at their center, giving rise to a cyst formation known as a syrinx, which, by its pressure, destroys the crossing fibers of the pain-temperature pathway, thus explaining the more or less symmetrical involvement of the two sides.

NOMENCLATURE. *Syringomyelia* is also spoken of as *central gliosis*. It is probable that in its incipency the disorder is due to an increase of the neuroglia or ependymal cells in the central gray matter which subsequently give rise to a cyst-like dilatation.

VARIATIONS. It is only in its early stages that syringomyelia manifests the limited clinical symptoms enumerated in this patient. The subsequent course of this particular case developed some of the more important variations to which the disease is subject. This patient later presented a marked atrophy in the hands and in the forearms. Such a change is indicative of the extension of the cyst so that it involved the ventral gray columns. Subsequently the patient noticed a stiffness in his legs, and great difficulty in walking. He had, in effect, a spastic paraplegia with an increase of all the deep reflexes, loss of the superficial reflexes, and the appearance of such pathological reflexes as the Babinski and crossed periosteal reflexes. These latter changes indicated the extension of the cyst into the lateral white columns. Ultimately there was a marked diminution of somesthetic sensibility, involving critical qualities in the trunk and legs, thus showing that the cyst had invaded the dorsal white columns of the cord. These are but a few of the many variations to which syringomyelia is subject, due to the irregular extension of the slowly dilating cyst.

Usually the cyst forms at the level of the cervical segments of the cord. More rarely it begins lower down in the thoracic and even in the lumbar segments. Under such circumstances the symptoms take their character from and have their distribution in accord with the level of the primary involvement.

SUMMARY. The essential clinical features of syringomyelia are:

(1) The loss of pain and temperature sensibility with the retention of critical tactile, joint, muscle, pressure and vibratory sensibility (*syringomyelic sensory dissociation*).

In addition to this, as a result of the extension of the lesion, there is usually a combination of:

(2) Atrophy and other trophic changes in the parts supplied by the segments of the primary lesion, and

(3) Spastic paralysis of the upper motor neurone type in parts supplied by segments below the level of the lesion.

SYNDROMES OF THE WHITE MATTER

Syndrome of the Dorsal White Column. HISTORY. A woman of middle life began to notice some numbness and tingling in her fingers. She had increasing difficulty in the performance of finer skilled acts, such as sewing and playing the piano. She found that her hands were not steady; that she could not, on this account, thread her needle or strike the proper notes on the keyboard. In the course of two months, a similar defect became apparent in her lower extremities. Her feet felt numb and cold. There was a tingling sensation in her legs and thighs. In walking, her steps became inaccurate and she was compelled to watch her feet constantly in order to keep from falling. She had no proper sense of motion in her legs, and as she walked she staggered and swayed from side to side. She had not lost strength in her limbs, but she did not possess the necessary feeling in them to guide her locomotion properly. Her condition in these respects became gradually worse.

EXAMINATION. (a) *Status of the Somatic Motor Component.* Volitional control and muscle strength were found to be normal. Equilibratory control in all tests showed a marked defect, as did also synergic control. On the other hand, automatic associated control was normal. There was a considerable reduction in the myotonus and also in the reflex activity. Idiodynamic control was normal in all respects.

(b) *Status of the Somatic Sensory Component.* The patient's complaint comprised disturbances in sensation described as tingling, numbness, a sense of cold and improper recognition of feeling in the limbs, all of which indicated the presence of marked dysesthesia (defective sensibility).

Objectively, she showed a decrease in the muscle-joint sensibility, in vibratory sense, in tactile discrimination and in deep and superficial pressure. Light stroking with a camel's hair brush or cotton wool was often inaccurately interpreted over her legs, arms and trunk. The neck, head and face showed no sensory disturbances. Temperature sensibility and affective tactile sensibility, together with the hurt element, were retained.

(c) *Status of the Splanchnic Motor Component.* This was normal.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of any pathological change in this element of the central nervous system.

INTERPRETATION AND ANATOMICAL ANALYSIS. The history indicates a slowly progressive and degenerative lesion.

The evidence of the focus of the lesion places the pathological process in the somatic sensory component. The allomeric distribution indicates a suprasegmental involvement. There is some interruption in the flow of influences dependent upon the cerebrum. This may be either in the brain or in the spinal cord. Lesions in the brain are usually unilateral; in the spinal cord they are more apt to be bilateral. The bilateral distribution of the symptoms in this case, therefore, points to the spinal cord.

The defects in discriminative sensibility with intact affective sensibility indicate the dorsal white column. Symptomatically, the sensory dissociation

is in contrast to that observed in syringomyelia, for here pain and temperature are unaffected. This type of sensory disturbance is known as *tabetic sensory dissociation*. The lowered reflexes and diminished muscle tone point to some defect in the reflex arc which may be explained by involvement of the reflex collaterals passing in the entrant zone close to the dorsal columns.

The evidence of circumscription of the lesion exempts the remaining white columns of the cord. There is no indication of loss of volitional control or muscle strength. The loss of synergic control is due to the lack of proper muscle and joint sensibility. There is no indication of defect in the ventral, lateral or dorsal gray columns, nor in the central gray commissure,

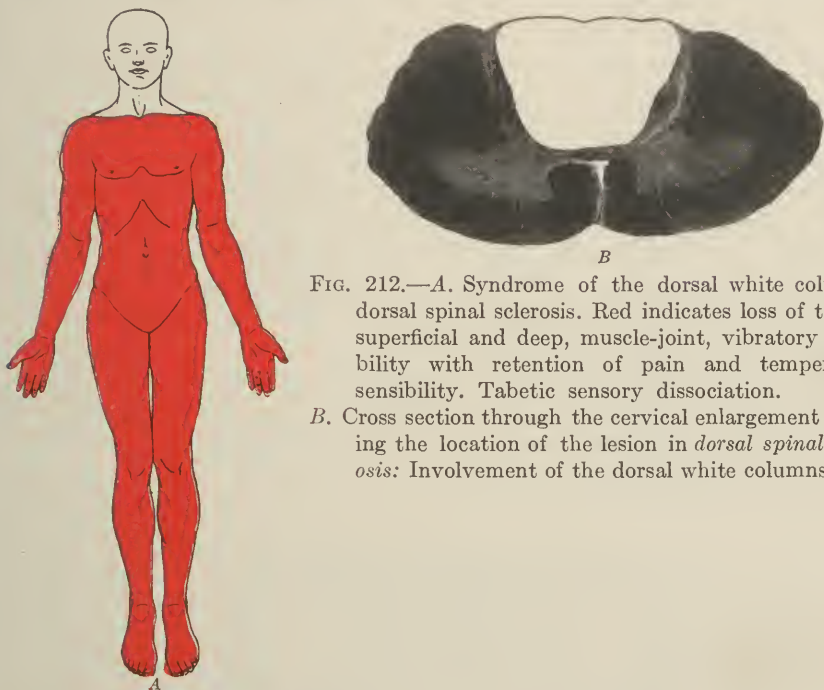


FIG. 212.—A. Syndrome of the dorsal white columns: dorsal spinal sclerosis. Red indicates loss of tactile, superficial and deep, muscle-joint, vibratory sensibility with retention of pain and temperature sensibility. Tabetic sensory dissociation.

B. Cross section through the cervical enlargement showing the location of the lesion in *dorsal spinal sclerosis*: Involvement of the dorsal white columns.

nor in the dorsal root ganglia. The focus of the lesion is, therefore, in the dorsal white columns of the spinal cord.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is *dorsal spinal sclerosis* caused by degenerative changes in the dorsal white columns. The lesion is situated in the cervical enlargement.

NOMENCLATURE. This disease is known as *dorsal spinal sclerosis*, *primary dorsal sclerosis*, *sensory spinal ataxia* or *spinal tabetic sensory dissociation*.

VARIATIONS. The distribution of the sensory disturbance in this disease is subject to considerable variation, dependent upon the height of the lesion. Usually the focus of the lesion is in the cervical region. It may, however, be lower down, involving either the thoracic or upper lumbar segments of the cord.

SUMMARY. The essential features of dorsal spinal sclerosis are:

- (1) Loss of critical sensibility in the legs and arms with the retention of pain and temperature sensibility (tabetic sensory dissociation).
- (2) Loss of coordination, producing ataxia in locomotion and in other skilled acts.
- (3) Reduction of the deep reflexes and muscle tone.
- (4) Normal myosthenic and myotrophic condition.

Syndrome of the Lateral White Column. HISTORY. A man, aged thirty-four, who had always been active in business, noticed the gradual development of fatigue upon walking and especially upon going upstairs. His legs felt heavy and stiff. In the course of several months this stiffness became more pronounced. He suffered no pain and no sensory disorder of any kind. His only inconvenience was a greater difficulty in locomotion occasioned by the stiffness in his legs. Gradually this stiffness increased until he was unable to lift either foot from the ground in walking; he dragged each foot. In fact, his entire leg was stiff and moved as one piece from the hip to the ankle. The stiffness increased so much that the adductor muscles held his thighs closer together, and in walking one foot was passed in front of the other, producing what is known as the "scissors-gait." This sort of cross-legged progression was ultimately attended by a kind of spring-like oscillation in the entire body, due to the fact that at each step the foot was moved by a clonic contraction of the muscles. In acts other than those concerned in locomotion it was difficult for the patient to move his feet, his legs or his thighs. No other motor or sensory elements in his body were affected. His condition grew progressively worse and he finally became bedridden.

EXAMINATION. (a) *Status of the Somatic Motor Component.* Upon examination, it was found that there was a marked loss of volitional control in both lower extremities. The voluntary control of the arms and the rest of the body was normal. The degree of rigidity in all the muscles of both lower extremities was such as to offer much resistance to all passive movements, while the amount of voluntary paralysis made it impossible to estimate to what degree equilibratory or synergic control remained intact. All automatic associated movements were increased, and many abnormal movements of this type could be elicited by proper testing. The myotonic control of the muscles has already been referred to as showing a marked hypertonus in the muscles of the lower extremities. The reflexes were correspondingly increased in their activity, especially those at the knee and ankle. Certain pathological reflexes were also observed, among them being a patellar and ankle clonus, the Babinski and the crossed periosteal reflex. The abdominal reflexes were all absent. The idiodynamic control of the muscles of the leg and trunk showed no departure from the normal.

(b) *Status of the Somatic Sensory Component.* No subjective disorders of sensation were observed in connection with this case, nor did the most careful testing for objective disturbances bring to light any change of somesthetic sensibility.

(c) *Status of the Splanchnic Motor Component.* There was no defect observed in this element of the nervous system.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of pathological change in this element of the nervous system.

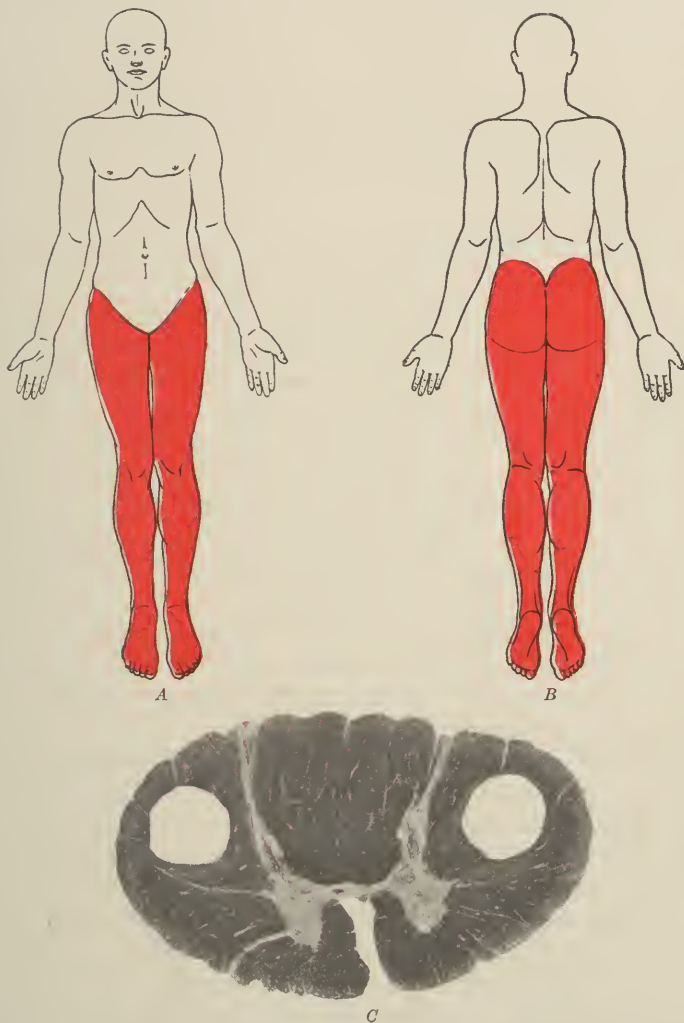


FIG. 213.—A and B. Syndrome of the lateral white column: Primary lateral sclerosis. Red indicates a spastic paraplegia with increase in the deep reflexes and pathological reflexes.

C. Cross section through thoracic segment showing the location of the lesion in *primary lateral sclerosis*: Involvement of the pyramidal tracts.

INTERPRETATION AND ANATOMICAL ANALYSIS. This case indicates a chronic progressive degenerative process affecting the nervous system.

The evidence of the focus of the lesion indicates an involvement of the somatic motor component. The fact that this involvement is clinically

bilateral points to the cord rather than the brain. The positive evidence favors the supposition that the pathological process involves allomeric functions and is, therefore, in the white matter. Since the chief pathway for the conduction of volitional impulses lies in the lateral white column, it is fair to presume that the principal lesion is situated in this area. The special tracts affected are the lateral pyramidal fasciculi. The level of the lesion is situated between the lower portion of the cervical enlargement and the mid-thoracic segments. This level is selected because of the freedom from involvement of the arms, thus indicating the upper limit of the lesion, and because of the absence of abdominal reflexes whose centers are situated in the lower thoracic region.

The evidence of circumscription of the lesion shows that the ventral gray column is not affected, since there is no myotrophic disturbance. The absence of any sensory changes exempts the dorsal white column, the dorsal root ganglia, the dorsal gray column and the gray commissure.

The lesion, therefore, is situated in the upper thoracic segments of the cord, is bilateral, and is confined to the lateral white column, especially involving the pyramidal tracts.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is *primary lateral sclerosis*. The pathological process consists of a sclerotic change involving the pyramidal tracts on both sides.

NOMENCLATURE. In addition to the term *primary lateral sclerosis*, this disease is also known as *primary spinal paraplegia*, and *spastic spinal paralysis*.

VARIATIONS. Primary lateral sclerosis is subject to few variations. Its symptoms are always those of an upper motor neurone type of paralysis and the distribution of this paralysis may vary somewhat with the height of the lesion. It rarely involves the cervical portion of the spinal cord.

SUMMARY. The essential features of primary lateral sclerosis are:

- (1) Spastic paraplegia.
- (2) Increase of the deep reflexes, appearance of pathological reflexes in the legs, such as the Babinski and the crossed peristoleal, and the absence of the abdominal reflexes.
- (3) The normal condition of idiodynamic control of the muscles, no wasting, loss of contour or reaction of degeneration.
- (4) The normal condition of all types of sensibility.

Syndromes of the Dorsal and Lateral White Columns Combined. In certain well-defined symptom-complexes due to involvement of the spinal cord, the pathological changes simultaneously affect the dorsal and lateral white columns. Two such syndromes may be considered in this connection:

Syndrome of Combined Sclerosis. **HISTORY.** A woman, forty-five years of age, with a good family history, previously energetic as well as capable, gradually became conscious of a general failure of health. She experienced a loss of strength and initiative, was conscious of fatigue most of the time and was unable to carry on her

usual occupation. She had the appearance of having a profound anemia. At the end of several months she noticed that walking caused fatigue. Her legs became stiff and locomotion on this account was progressively more difficult. She noticed that her greatest trouble was in going up-stairs, and that in walking on the level there was a tendency for one foot to cross in front of the other. This she could prevent only by an extreme effort of the will. On certain occasions when sitting, she noticed that both legs trembled and shook, especially if the foot was placed in such a way that the heel was lifted from the floor. She finally became so anemic and physically depressed that it was necessary for her to remain in bed. In several months her general condition improved and she was able to get up and go about again. At this time, she noticed a marked change in locomotion. On attempting to walk, she had a peculiar sensation as of pins and needles in the feet and legs, and seemed to have an imperfect perception of how her muscles were acting, so that in walking it was necessary for her to watch the ground with care. If she were inattentive in this regard, she began to stagger, even to lose her balance and fall. Her legs were no longer stiff, nor did she have any of the peculiar tremor which had been noticed, especially when sitting down. An examination of her blood at this period showed that she was suffering from *pernicious anemia*.

EXAMINATION. Several examinations of the patient during the course of her disease showed the following changes:

(a) *Status of the Somatic Motor Component.* During the early stages of the disease, volitional control was appreciably defective, as was also the strength of the muscles in the legs. The gait was spastic, due to a marked increase in the tonus of the muscles. The deep reflexes were all more active than usual; there was patellar and ankle clonus, a bilateral Babinski and a bilateral crossed periosteal reflex. Equilibratory and synergic control were both normal in so far as they were not impaired by this spasticity of the muscles. Idiodynamic control remained normal throughout the entire course of the disease.

During the second stage of her disorder, particularly during the period after she had recovered from her first acute anemic depression and was able to walk again, the symptoms of muscular spasticity and defective volitional control were replaced or overshadowed by a loss in equilibratory and non-equilibratory coordination, and also by the complete disappearance of all the deep reflexes.

(b) *Status of the Somatic Sensory Component.* In the early stages of the disease, the patient showed little or no subjective or objective change in somesthetic sensibility. Subsequently, however, such changes were present in marked degree. The patient complained of certain dysesthesia, principally numbness and a feeling of cold in the legs. No pain was complained of at any time. Objective investigation of sensibility showed that all types of critical sensation were seriously affected, including muscle, joint, vibratory, and tactile discrimination. To some degree also affective sensibility was involved, pain and temperature stimuli both showing a

marked retardation in transmission as well as considerable confusion in perception.

(c) *Status of the Splanchnic Motor Component.* No changes were observed in this part of the nervous system.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of pathological alteration in this component.

INTERPRETATION AND ANATOMICAL ANALYSIS. The history of this case shows a chronic progressive involvement of the nervous system in consequence of or in combination with pernicious anemia.

The evidence of the focus of the lesion indicates a successive involvement, first, of the somatic motor component, and subsequently, of the somatic

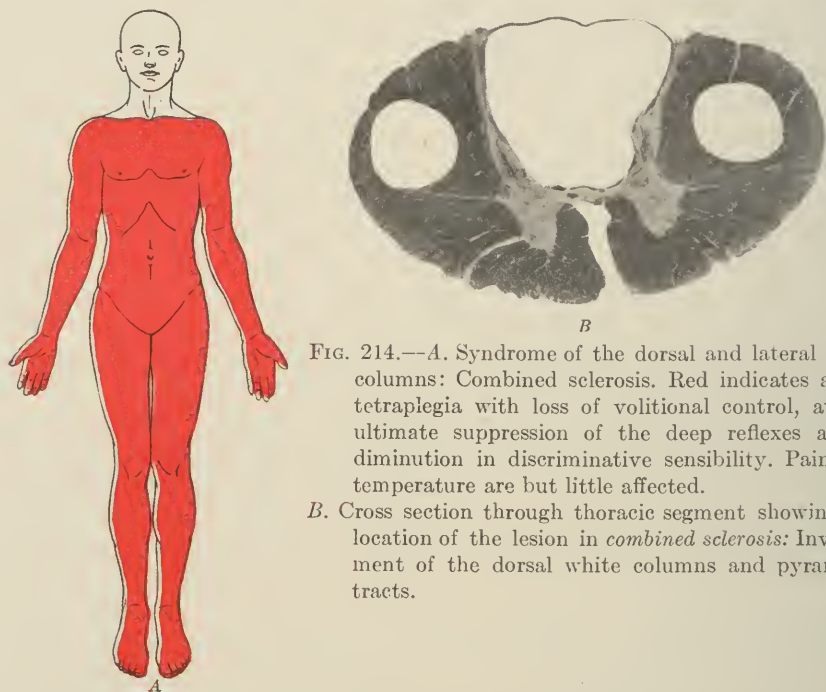


FIG. 214.—A. Syndrome of the dorsal and lateral white columns: Combined sclerosis. Red indicates ataxic tetraplegia with loss of volitional control, ataxia, ultimate suppression of the deep reflexes and a diminution in discriminative sensibility. Pain and temperature are but little affected.

B. Cross section through thoracic segment showing the location of the lesion in *combined sclerosis*: Involvement of the dorsal white columns and pyramidal tracts.

sensory component. The bilateral distribution of this disorder to both legs would indicate a cord rather than a cerebral lesion. The symptoms in the early stage of the disease were those of a spastic spinal paraplegia, indicating a lesion in the lateral white column. Later the symptoms were those of a spinal sensory ataxia, thus pointing to a disorder which combines the characteristics of primary lateral sclerosis and primary dorsal sclerosis.

The evidence of circumscription of the lesion indicates that the ventral gray column, the dorsal gray column and dorsal root ganglia, were not affected by the pathological changes. The conclusion, therefore, is that the pathological alterations were confined to the lateral and dorsal white columns. In the latter columns, the pyramidal tracts and probably the spino-thalamic tracts were affected, while all of the tracts in the dorsal columns were in-

volved, together with reflex collaterals crossing in the entrant zone of the dorsal root.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is *combined sclerosis*. This is due to the pathological alteration in the pyramidal tracts and in the dorsal white columns, almost symmetrically and bilaterally disposed. It has been assumed by some authorities that pernicious anemia determines a toxic condition as the result of which degenerative changes take place in the central nervous system. There are those, however, who maintain that the pernicious anemia is coincident with the changes in the spinal cord.

NOMENCLATURE. This disease is known as *combined sclerosis* and as *lateral and dorsal sclerosis complicating pernicious anemia*.

VARIATIONS. Many cases of this disease show an involvement of the arms as well as of the legs. When this latter is the case, however, the changes in the arms are largely confined to disorders in sensibility. The disease is subject to marked fluctuations, the patient presenting periods in which all the symptoms are at a minimum, and others in which each symptom is developed to an extreme degree.

SUMMARY. The essential clinical features of combined sclerosis are:

(1) The successive appearance of primary lateral sclerosis shortly followed by all the symptoms of dorsal spinal sclerosis; that is to say, a spastic spinal paraplegia complicated by spinal sensory ataxia.

(2) The absence of all evidence of involvement of the ventral gray column, of the dorsal gray column or of the dorsal root ganglia.

Syndrome of Friedreich's Ataxia. **HISTORY.** A girl, eleven years of age, began to notice that she stumbled and fell in play. This difficulty slowly increased until it became apparent even in walking. She was conscious of considerable difficulty in movements of the hands and fingers, especially in writing and needlework. This condition grew progressively worse for about a year, at which time her younger brother, nine years of age, began to complain of the same difficulty in running, walking, and the finer movements of the hands.

EXAMINATION. When examined at this time, the girl showed the following conditions:

(a) *Status of the Somatic Motor Component.* The volitional control and muscular strength were nearly normal, but the equilibratory and non-equilibratory control were both much impaired. All tests for equilibratory coordination showed marked defects. Non-equilibratory coordination, likewise, developed extreme ataxia. Automatic associated control was normal. The muscle tone was much reduced in the arms and legs, but much increased in the feet, where it produced an extreme arching known as "pes cavus." The deep reflexes were feeble in the arms and absent at the knee. Of the superficial reflexes, the abdominals were absent, but a Babinski was present on both sides. The idiodynamic control was normal.

(b) *Status of the Somatic Sensory Component.* The patient complained neither of pain nor of any other subjective change in sensibility. Upon

examination, however, a slight diminution in all types of sensation was found, but more marked in the muscle, joint, tactile discrimination and vibratory sensibility. This defect was limited to the legs and feet.

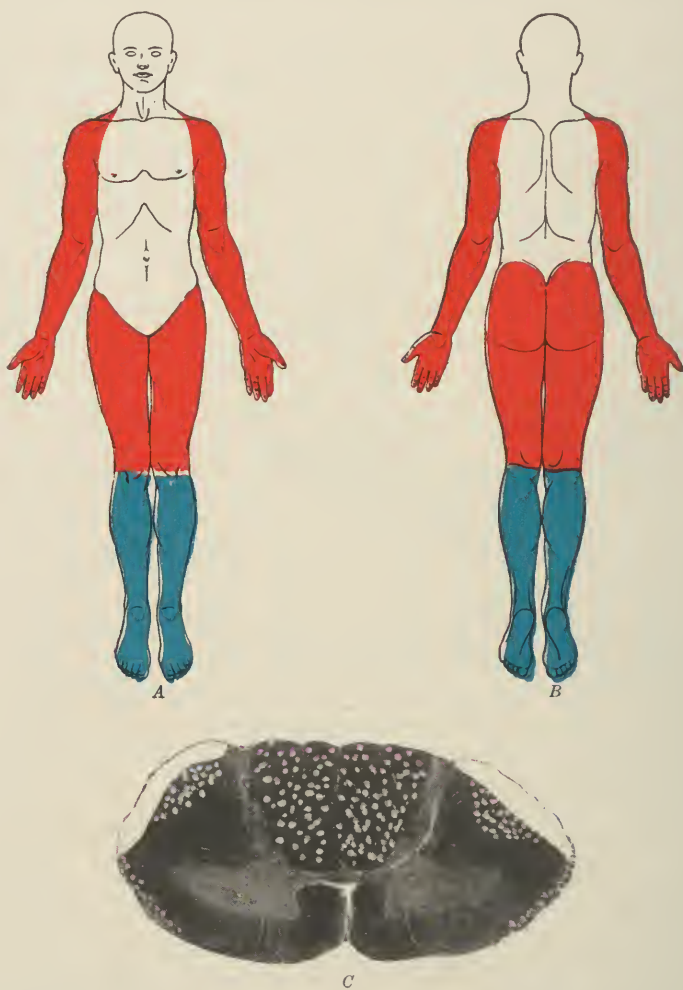


FIG. 215.—A and B. Syndrome of Friedreich's ataxia. Red indicates equilibratory and non-equilibratory ataxia and absence of the knee-jerk. Blue indicates in addition to the preceding a diminution in all types of sensibility, especially the discriminative type.

C. Cross section through the cervical enlargement showing the location of the lesion in *Friedreich's ataxia*: Involvement of the spino-cerebellar and pyramidal tracts and the dorsal white columns.

(c) *Status of the Splanchnic Motor Component.* This element revealed nothing abnormal.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of pathological change in this component.

INTERPRETATION AND ANATOMICAL ANALYSIS. The history indicates a progressive and familial disease affecting the nervous system, involving two members of the same generation, a brother and a sister.

The evidence of the focus of the lesion points to the somatic motor component, as well as to the somatic sensory component. This appears to be in the cord rather than in the brain, because of the bilateral distribution of the disturbances. It seems probable that the lesion is in the white matter because it was the allomeric functions of the spinal cord which showed defect. A lesion in the circumferential white matter of the lateral column would give a marked degree of ataxia in the absence of pronounced sensory disturbances in the muscle-joint sense. On the other hand, in order to explain such changes in sensibility as do occur, it is necessary to predicate some pathological change in the dorsal white column.

The evidence of circumscription of the lesion furnishes no signs referable to disturbance of the ventral or dorsal gray matter.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is *Friedreich's ataxia*, which is due to a progressive degenerative disease in the dorsal and lateral white columns of the spinal cord.

NOMENCLATURE. This disorder, while usually known as *Friedreich's ataxia*, is also called *hereditary spino-cerebellar ataxia* and *familial spino-cerebellar ataxia*.

VARIATIONS. The disease varies considerably both in its severity and in the concomitance of other symptoms. Not infrequently choreiform movements appear. These may be in consequence of involvement of the rubro-spinal tract, thus adding an efferent cerebellar motor disturbance to the clinical picture. In the early stages the ataxia is slight, but after the disease progresses it may become so severe that the patient becomes bedridden.

SUMMARY. The essential clinical features of this disease are as follows:

- (1) Ataxia in all skilled movements.
- (2) A familial or hereditary history and a progressive course.
- (3) Absence of the knee-jerks and the presence of a bilateral Babinski.
- (4) The presence of a *pes cavus*, and hypotonus of the muscles in the legs and arms.

SYNDROMES OF THE GRAY AND WHITE MATTER

Syndrome of the Lateral White and Ventral Gray Columns. HISTORY. A man, forty years old, began to notice a stiffness in his hands and arms, which was regarded as rheumatism, although he suffered no pain. In the course of six months, his hands and forearms began to waste and with the atrophy of the muscles there also came definite contractures producing a fixed position of the forearm at the elbow, and holding the fingers in flexion. At the end of a year, his legs were stiff and walking had become difficult. Finally his gait assumed all the characteristics of a spastic

paraplegia. By this time he had lost nearly all power in his hands, and the muscles of his upper extremities were in a more or less constant state of fibrillary tremor. He had no sensory disturbances of any kind.

EXAMINATION. When examined at this time he showed the following:

(a) *Status of the Somatic Motor Component.* Volitional control and strength in both legs and arms were greatly reduced. Equilibratory, coordinative and automatic associated control could not be estimated, as they were masked by the volitional motor defect. Muscle tone was increased in both arms and legs. The reflexes in both upper and lower extremities were very active. There was a bilateral ankle clonus and a bilateral Babinski. The abdominal reflexes were all absent. The muscles in both hands and fore-

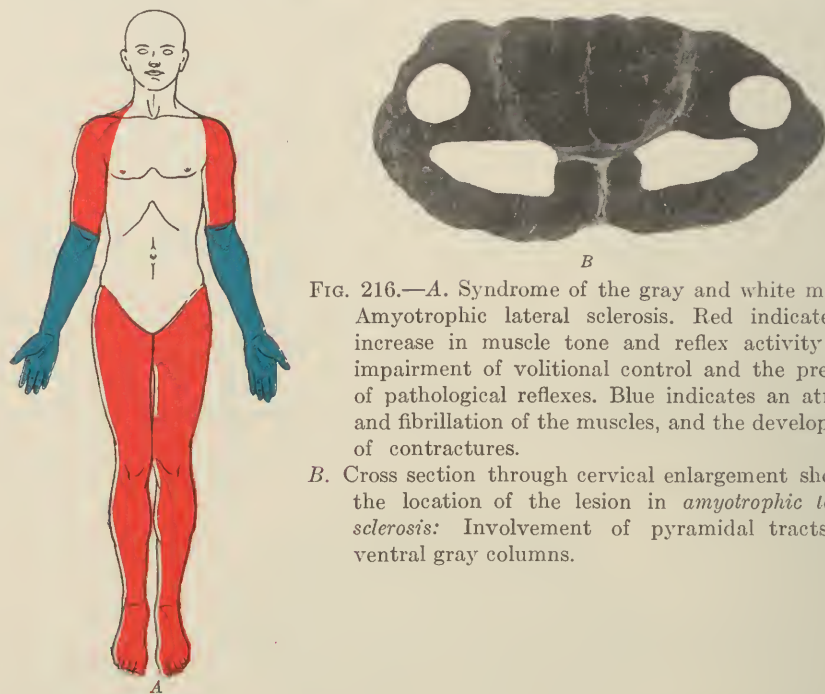


FIG. 216.—A. Syndrome of the gray and white matter: Amyotrophic lateral sclerosis. Red indicates an increase in muscle tone and reflex activity with impairment of volitional control and the presence of pathological reflexes. Blue indicates an atrophy and fibrillation of the muscles, and the development of contractures.
B. Cross section through cervical enlargement showing the location of the lesion in *amyotrophic lateral sclerosis*: Involvement of pyramidal tracts and ventral gray columns.

arms were much wasted and presented the reaction of degeneration, together with fibrillary tremors. No such changes were apparent in the lower extremities.

(b) *Status of the Somatic Sensory Component.* There were no pathological changes in this component.

(c) *Status of the Splanchnic Motor Component.* This was normal.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of pathological alteration in this element of the nervous system.

INTERPRETATION AND ANATOMICAL ANALYSIS. The history is that of a chronic, progressive disease, degenerative in its character.

The evidence of the focus of the lesion shows that the pathological process has involved the somatic motor component in the gray and the white

matter. The location is in the cord, because of the bilateral distribution of the symptoms. The disturbances in the arms are due to involvement of the gray matter, while those in the legs are caused by defects in the white matter. In the arms there is loss of volitional control and idiodynamic control. The spastic paraplegia is indicative of an involvement in the lateral white column, especially affecting the pyramidal tracts.

The evidence of circumscription of the lesion shows no sign referable to the dorsal gray or white column. The lesion, therefore, involves both lateral white and ventral gray columns.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is *amyotrophic lateral sclerosis*. The pathology of the condition is a progressive degenerative change, first involving the pyramidal tract in the cervical segments and then extending to the ventral gray column.

NOMENCLATURE. *Amyotrophic lateral sclerosis* is also known as *spastic spinal paralysis with atrophy*.

VARIATIONS. The degree both of the atrophy and the spastic paralysis varies considerably in different cases, but in all instances the diagnosis demands some evidence indicating a lesion affecting simultaneously or consecutively the white matter of the lateral column and the gray matter of the ventral column.

SUMMARY. The essential clinical features of amyotrophic lateral sclerosis are:

(1) Spastic paralysis of the legs with pathological and increased deep reflexes. This includes the ankle clonus and Babinski.

(2) Atrophy with reaction of degeneration and fibrillary tremors in the forearms and hands.

(3) Increased reflexes in the arms.

(4) Absence of sensory changes in any part of the body.

Syndrome of Hemisection of the Spinal Cord. **HISTORY.** A soldier, shot in the back by a machine gun, was found upon operation to have sustained a fracture of the lamina of the sixth thoracic vertebra upon the left side. As a result of this injury, a sharp spicule of bone had been driven forward in such a way as to cut completely through the left half of the spinal cord. In consequence, he had a complete paralysis of the left leg.

EXAMINATION. On examination two months after the operation, he showed the following:

(a) *Status of the Somatic Motor Component.* The patient suffered from a complete loss of all volitional control and muscle strength in the muscles of the left leg. The other musculature of the body was normal. There was a marked increase in the tone of all the muscles of the left leg, together with an increase of the deep reflexes, including an ankle clonus and a Babinski. The muscle tone, idiodynamic control and reflexes elsewhere in the body were normal.

(b) *Status of the Somatic Sensory Component.* The patient complained of no subjective alteration in sensibility. Upon examination, it was found

that objectively he had a complete loss of tactile, joint, muscle, and vibratory sense, as well as of tactile discrimination in the left leg. Pain and temperature sensibility in the left leg remained intact. In the right leg, however,

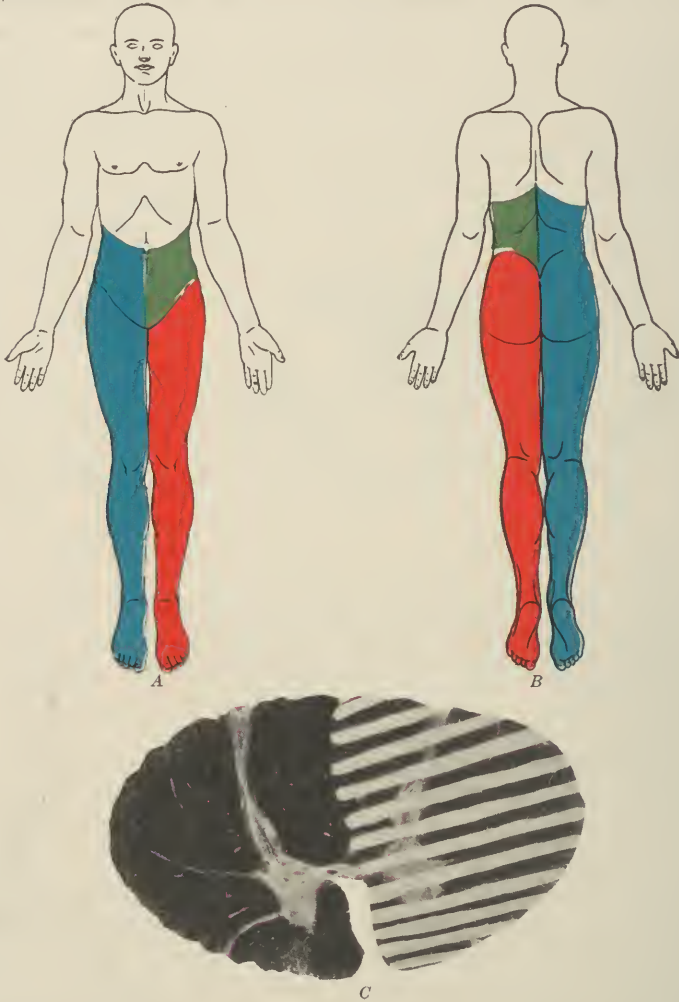


FIG. 217.—A and B. Syndrome of hemisection of the cord: Syndrome of Brown-Séquard.

Red indicates a spastic monoplegia of the left leg with a complete loss of volitional control and the presence of abnormal reflexes, in addition a complete loss of the discriminative types of sensibility with a retention of the affective types of sensibility.

Blue indicates a complete loss of affective sensibility, pain and temperature. Green indicates a complete loss of discriminative sensibility.

C. Cross-section through the sixth thoracic segment showing the location of the lesion in the syndrome of Brown-Séquard: Involvement, hemisection of the cord.

while there was a complete retention of joint, muscle, vibratory and tactile discrimination, there was an entire loss of pain and temperature sensibility. The zone of this disturbance upon both sides extended to a level upon the trunk corresponding to the 8th thoracic dermatome.

(c) *Status of the Splanchnic Motor Component.* This was normal.

(d) *Status of the Splanchnic Sensory Component.* There was no evidence of pathological change in this component.

INTERPRETATION AND ANATOMICAL ANALYSIS. The history shows the case to be one of traumatic incidence.

The evidence of the focus of the lesion indicates that the injury affected the somatic motor and the somatic sensory components. This evidence points directly to an interruption in the lateral and dorsal white columns, including the pyramidal and spino-thalamic tracts, together with the tracts of Goll and Burdach. The defect is limited to the left side of the cord.

The evidence of circumscription of the lesion because of the absence of any disturbance in critical sensibility and absence of spastic paralysis upon the right side of the body, and the presence of pain and temperature sensibility upon the left side, indicates that the right half of the cord is still intact. There were no signs referable to the ventral or dorsal gray matter, nor to the central gray.

DIAGNOSIS AND PATHOLOGY. This is known as the *syndrome of hemisection of the cord*, and is usually due to the partial separation of the cord by trauma.

NOMENCLATURE. The syndrome of hemisection of the cord is also known as the *syndrome of Brown-Séquard*.

VARIATIONS. The degree of paralysis, as well as the sensory disorders, depend upon the extent, level and angle of the hemisection. Many variants of this syndrome have been clinically noted.

SUMMARY. The essential clinical features of the Brown-Séquard syndrome are:

(1) Spastic paralysis and loss of critical sensibility ipsilateral with the lesion.

(2) The loss of pain and temperature sensibility contralateral to the lesion in areas corresponding with but opposite to the paralyzed parts.

(3) The absence of sensory and motor disturbances in other parts of the body.

Syndrome of Complete Section of the Spinal Cord. HISTORY. A soldier shot in the back was immediately paralyzed in both legs and had complete loss of sensation in the lower part of his body and in both legs. He also lost control of the bladder and rectum. At operation, several days later, it was found that the bullet had passed in such a way as to cause complete separation of the spinal cord at the 9th thoracic segment.

EXAMINATION. When examined two months after the operation, he presented the following condition:

(a) *Status of the Somatic Motor Component.* There was a complete loss of volitional control and muscle strength in both legs. The patient was absolutely unable to make any movement with the muscles below the level of the umbilicus. The volitional control and muscle strength in the other muscles of the body were well preserved. There were no defects of equilibra-

tory or synergic control in the muscles innervated by segments above the level of the lesion, while the entire absence of all volitional control made it impossible to estimate the status of these functions below the lesion. The muscle tone in all the groups of muscles in both lower extremities was distinctly increased. The legs were held partly in flexion and rigidly adducted. All of the deep reflexes were extremely active. There was a bilateral patellar and ankle clonus and a bilateral Babinski. The abdominal reflexes were absent. The reflexes in both upper extremities were active and equal. They manifested no pathological change. The idiodynamic control of the muscula-

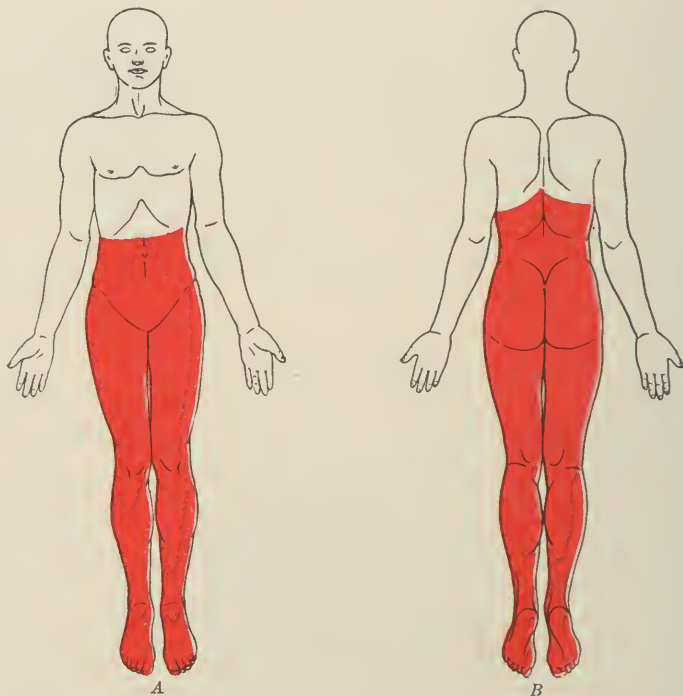


FIG. 218.—A and B. Syndrome of complete section of the spinal cord. Red indicates complete paralysis of the body and legs; complete loss of all types of discriminative and affective sensibility; loss of bladder and rectal control.

ture of the whole body at this period was normal. There was no reaction of degeneration, but little wasting of the muscles, a slight loss of contour in the muscle bellies and no fibrillary tremors.

(b) *Status of the Somatic Sensory Component.* The patient complained of certain sensory disturbances; he had lost all perception of the position of his limbs and said he felt as if his legs had been detached from his body. He complained of a slight pain in the back in the region of the operative wound.

Objectively, there was found to be complete loss of all types of sensibility in all the dermatomes up to and including the 9th thoracic dermatome.

(c) *Status of the Splanchnic Motor Component.* There was complete loss of control of the bladder and rectum and marked evidence of reduced trophic resistance of the skin which showed a tendency to decubitus (bed sores).

(d) *Status of the Splanchnic Sensory Component.* There was no evidence indicating pathological alteration in this part of the central nervous system.

INTERPRETATION AND ANATOMICAL ANALYSIS. The history shows the case to be traumatic in origin.

The evidence of the focus of the lesion indicates a level of the spinal cord with the upper limit of the injury at the 9th thoracic segment. This is substantiated by the complete absence of function in the white matter of both the lateral and dorsal columns below the level of injury.

The evidence of circumscription of the lesion indicates that the spinal cord above the 9th thoracic segment is functioning normally.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is *complete traumatic separation of the spinal cord*. The pathology takes its character from the destruction occasioned by the injury.

NOMENCLATURE. This condition is known as complete traumatic division or separation of the spinal cord.

VARIATIONS. The variations of this syndrome are numerous, the two chief types depending upon the nature of the injury which produced the disorder, and the time after the injury at which the patient is seen. Crushing injuries of the spinal cord not only cause pathological changes at the site of the injury, but also render the cord abnormal for a considerable distance both above and below the site of the injury. Incised wounds are much less likely to have a diffuse effect upon the cord than the crushing injuries already mentioned. Cases of the diffuse type usually show a more or less complete flaccid paralysis during the entire course of the disease. In some instances, however, this initial flaccid paralysis may be replaced by spastic paralysis with increased reflexes, clonus and Babinski.

The appearance of spastic paralysis following complete separation of the cord due to incised wounds and bullet wounds is much more rapid than in the case of crushing injuries. These two elements, namely, the character of the trauma producing the lesion, and the time elapsed between the receipt of the injury and the examination of the patient, have led to much controversy concerning complete division of the spinal cord.

SUMMARY. The essential clinical features of complete division of the spinal cord immediately after the injury are:

(1) Immediate complete flaccid paralysis of all muscles below the level of the lesion.

(2) Immediate complete loss of all types of sensibility below the level of the lesion.

(3) The loss of bladder and rectal control.

(4) Normal sensory and motor conditions above the level of the lesion.

The essential features of complete division of the spinal cord in cases seen several months after receiving the injury may be:

- (1) Complete spastic paralysis of all the muscles below the level of the lesion.
- (2) The presence of increased reflexes, clonus and Babinski.
- (3) A complete loss of all types of sensibility up to the level of the lesion.
- (4) Loss of bladder and rectal control.
- (5) Normal motor, sensory and visceral conditions in the parts of the body supplied by the segments above the level of the lesion.

CHAPTER XIII

REMOVAL OF THE BRAIN AND INVESTIGATION OF THE BRAIN-CASE

The Cephalic Division of the Central Nervous System. The second of the two major divisions of the central nervous system is the *brain* or *encephalon*. A satisfactory examination of this organ should include not only the study of the brain itself, but also the bony and membranous capsules which contain it. Many important clinical relations exist between the brain and the skull. Their significance cannot be appreciated unless the cranium is studied in conjunction with the encephalon at the time of removal.

PRELIMINARY PROCEDURE FOR THE REMOVAL OF THE BRAIN

Superficial Incision through the Scalp and Subcutaneous Tissues. A transverse incision is made across the vertex, beginning above one ear and ending above the other. This incision should pass down through the skin, subcutaneous tissue and the aponeurosis of the occipito-frontalis muscle. The cut edge should then be grasped with a piece of muslin or similar material in order to provide a firm grip, and the entire thickness of the tissue covering the cranium will strip readily both forward and backward. The anterior flap should be detached as far forward as the orbital ridges. The posterior flap should be turned back until the greater part of the occipital bone is exposed.

Removal of the Calvarium. **INCISION IN THE BONE.** The head should be placed in the concavity of a block hollowed out for that purpose, and a saw-line for removal of the calvarium should be lightly traced on the skull. This line should start at the midline anteriorly just above the *orbital ridge* and be carried outward and slightly downward to end just above the ear on each side. The cadaver should then be turned so that it lies on its face, and a second line traced from the region of the external occipital protuberance forward and downward to meet the line already described just above the ear. This superficial saw cut should then be deepened until the entire thickness of the skull is divided. Care should be exercised that the thin inner table is just cut through. Precaution against injury to the dura and brain is especially necessary at the curve of the forehead, which should not be sawn directly across, but the frontal region should be sawn first and then the saw directed along the lateral aspect of the cranium. The extreme thinness of the cranium in the temporal fossæ should be remembered in order to avoid injury to the brain. It may then be ascertained whether the calvarium is free

through its entire circumference, and any remaining pieces of bone can be broken through by means of a chisel and mallet. The calvarium may then be detached.

INCISION OF THE DURA. The dura should then be incised with a small knife in a cruciform manner, care being exercised not to injure the brain. The dura mater should then be reflected in order to expose to view the underlying structures. Along the great longitudinal fissure, the dura mater will be found to be closely connected with the arachnoid, the pia mater and the hemispheres by means of a number of veins which drain the cortex and empty into the superior longitudinal sinus.

THE ARACHNOID AND PIA MATER. Careful examination of the convexity of the hemispheres will show the *arachnoid* stretching over the fissures and convolutions and the *pia mater* carrying the arteries and veins of the cerebral circulation. On the surface of the arachnoid will be found granular areas, mainly near the great longitudinal fissure, which represent the *Pacchionian granulations* or the *arachnoidal villi*. Along the dorso-mesial border of the hemispheres will be found the torn ends of a number of veins which empty into the superior longitudinal sinus. These veins enter the sinus at an angle directed forward and inward, thus pouring their blood into the sinus against the direction of the stream-flow. Their trunks may be from twelve to fifteen in number.

REMOVAL OF THE BRAIN

The Anterior Cranial Fossa. In order to remove the brain from the skull, the tips of the frontal lobes should be gently raised. As this is done the orbital plates of the frontal bones and the cribriform plate of the ethmoid bone will become visible. In the center of the cribriform plate of the ethmoid will be seen the *crista galli* with the falx arising from its caudal margin. On either side of the crista, lying in shallow depressions on the cribriform plate of the ethmoid, will be seen the *bulbs* of the *olfactory tracts*, and passing caudally from them the olfactory tracts. The olfactory bulbs should be raised from the cribriform plate, and as this is done a number of very fine nerve fibers will be seen passing from the under surface of the bulbs through the foramina in the cribriform plate. These fibers are the *fila olfactoria* of the olfactory apparatus. The frontal lobes are then raised further from the orbital plates of the frontal bone, and the free caudal margins of the lesser wings of the sphenoid will make their appearance.

The Middle Cranial Fossa. In the midline will be seen the dorsal surface of the body of the sphenoid. Just behind the dorsal surface of the body of the sphenoid will be seen two thick nerve trunks located near the midline and directed forward and outward. These are the *optic nerves*. They are passing to their decussation in the optic chiasm, and enter the skull from the orbits through the *optic foramina*. The optic nerves are now divided and the brain raised. As a result, two large vessels make their appearance, one on each side, the *internal carotid arteries*, which in large part

supply the blood destined to the cephalic areas of the brain. The *optic chiasm* also makes its appearance, and directly behind it will be seen the slender *infundibular stalk* making its way from the under surface of the brain to disappear through a portion of the dura which stretches backward from the posterior edge of the dorsal surface of the body of the sphenoid; this membrane is the *diaphragma sellæ*. Laterally it stretches between the anterior, middle and posterior *clinoid processes* to form a membrano-osseous pocket in which is lodged the *hypophysis cerebri*. With the brain raised as far as possible, the point of a sharp knife should be passed through the *diaphragma sellæ* and the pituitary body will be drawn from its resting place, the *sella turcica*. Immediately behind the pocket in which the pituitary body is lodged, and forming the posterior boundary of the sella is a projecting plate of bone, the *dorsum sellæ*, which at its summit presents two tubercles, the *posterior clinoid processes*.

It will now be found that it is not possible to raise the brain further on account of a horizontal partition, the *tentorium cerebelli*, stretched across the posterior portion of the base of the skull and presenting at its center a space through which passes the brain-stem.

INCISION OF THE TENTORIUM. This partition should now be incised at its line of attachment from within outward and backward along the superior border of the petrous portion of the temporal bone.

NERVES OF THE OCULOMOTOR MECHANISM. External to and below the base of the *dorsum sellæ* will be found three nerves coursing forward on each side from the brain-stem to disappear by penetrating the dura at the base of the skull; the innermost of these is the *3d cranial nerve (oculomotorius)*. Lateral to this nerve is a fine nerve, the *4th cranial nerve (trochlearis)*, and another small nerve, the *6th cranial nerve (abducens)*. External to the mesial attachment of the dural partition separating the middle and posterior fossæ is a broad flat nerve penetrating the dura, the *5th cranial nerve (trigeminus)*, which should be divided close to its point of penetration into the dura.

The Posterior Cranial Fossa and Its Nerves. Having divided the fibrous partition attached to the superior border of the petrous portion of the temporal bone, it will be found that the brain can be more freely raised from the base of the skull. As it is raised, two nerves are seen coursing outward toward the *internal auditory meatus* on the postero-superior surface of the petrous portion of the temporal bone. These are the *7th and 8th cranial nerves*. They should be divided close to the internal auditory meatus.

Further traction on the brain will show a group of three nerves passing outward and slightly forward from the brain-stem toward the *jugular foramen*. They are situated almost directly posterior to the internal auditory meatus. These are the *9th (glossopharyngeus)*, *10th (vagus)*, and *11th (spinal accessory) cranial nerves*. They should be divided close to the jugular foramen.

Mesial to these nerves, and somewhat caudal, will be found the *12th*

cranial nerve (hypoglossal) passing forward from the brain-stem. This nerve should be divided, and the brain may then be removed. If the stem has not been divided at the foramen magnum, a long pair of scissors or a long knife may be passed into the foramen magnum ventral to the stem and the cord separated from the medulla. The brain should be removed gently and the reflection of the dura mater which will be found to lie between the cephalic surface of the cerebellum and the caudal surface of the cerebral

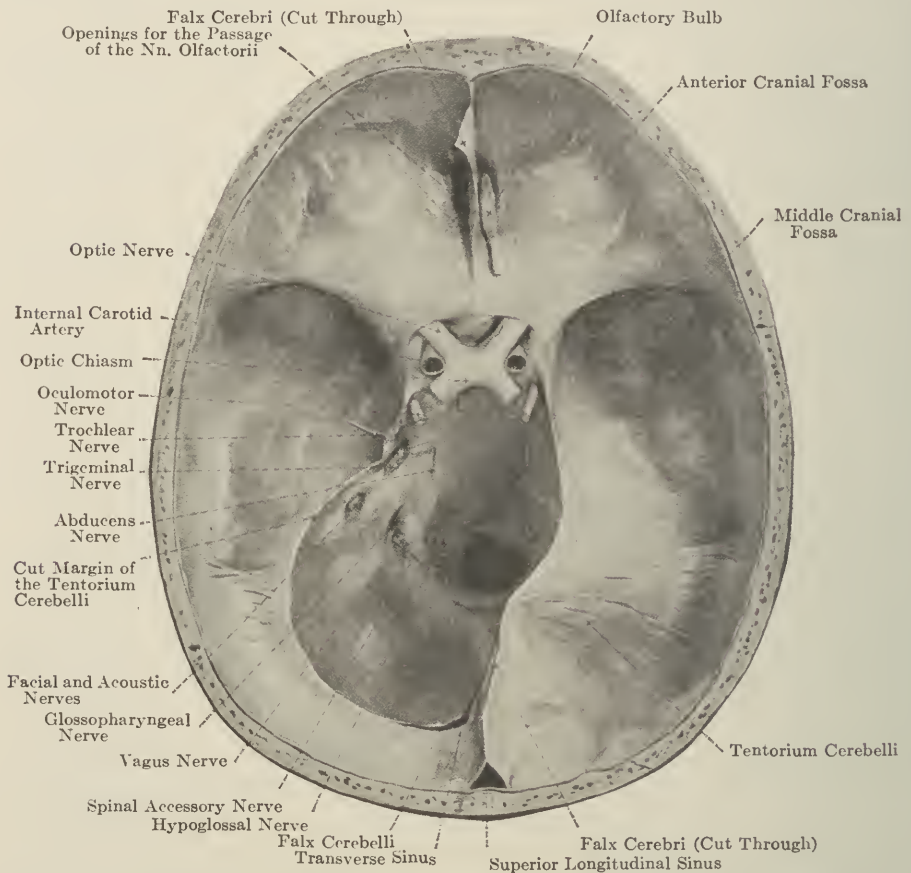


FIG. 219.—Dura mater viewed from above; the falx cerebri has been almost completely removed, the tentorium cerebelli on the left side only. (*Spalteholz.*)

hemispheres may be pulled away from these two structures. The brain should be placed in a jar sufficiently large to receive it without compression, and allowed to rest upon cotton. The jar should contain a 5 per cent solution of formalin. When sufficiently hardened, the brain may be further examined. Certain major divisions may be noted for study. These divisions are: the medulla, the pons Varolii, the cerebellum, the mid-brain, the interbrain and the cerebral hemispheres. Each of these parts requires separate description.

EXAMINATION OF THE DURA MATER COVERING THE BASE OF THE SKULL

After the removal of the brain the dura will remain attached to the base of the skull. The cut edge of the dura will be found around the circumference of the bony incision. The dura presents two layers, a tough, firm outer layer which is closely adherent to the bones of the skull and forms its periosteum, and a thinner, more delicate inner layer which is in contact with the arachnoid. The space between the dura and the arachnoid is the *subdural space*. It is in direct continuity with the lymph spaces in the sheaths of the cranial nerves. The subdural space does not communicate with the subarachnoid space. The dura will be found to be continued outward on the cranial nerves as they pass to their foramina of exit, where it becomes adherent to them and forms part of their sheath. The dura is more closely adherent to the bones of the skull over the base than over the vertex, especially at the suture lines and over prominences or irregularities of the bones. The space between the skull and the dura is the *epidural space*.

Upper Limit of the Ligamentum Denticulatum. At the foramen magnum the uppermost part of the ligamentum denticulatum will be found to divide into ventral and dorsal leaves which are applied respectively to the ventral and dorsal portions of the foramen on either side.

The Venous Sinuses. Coursing between the two layers of the dura mater will be found the great venous sinuses of the skull. In the middle fossa there are two such sinuses, the *circular* and the *cavernous sinuses*. The cavernous sinuses, two in number, arise at the mesial extremity of the sphenoidal fissures by the confluence of the ophthalmic veins, and pass backward in the folds of dura mater which close in laterally the pituitary fossa. The circular sinus is formed by two transverse limbs which pass across cephalically and caudally around the olivary eminence and connect the cavernous sinuses.

From the foramen spinosum, coursing upward and dividing into anterior and posterior branches, will be found the *middle meningeal artery*, which lies between the layers of the dura mater and supplies a large part of the membrane with nourishment.

In the posterior fossa there are a number of sinuses. At the dorsum sellæ the cavernous sinuses give rise to the *superior* and the *inferior petrosal sinuses*. The *superior petrosal sinus* runs along the superior border of the petrous-temporal bone and opens laterally into the curve of the *sigmoid sinus*. The *inferior petrosal sinus* passes backward and downward over the tip of the petrous-temporal bone to the mesial compartment of the jugular foramen, through which it passes. At a point corresponding to the external occipital protuberance will be found a depression on the internal surface of the occipital bone which is called the *torcular Herophili*. At this point the *superior longitudinal sinus* turns, usually to the right, and becomes the *right transverse* or *lateral sinus*. As the lateral sinus passes outward and forward, it reaches the postero-inferior angle of the parietal bone, where it turns downward, crosses the masto-temporal bone, reaches the jugular

process of the occipital bone, and enters the lateral compartment of the jugular foramen, through which it passes to unite with the *inferior petrosal sinus* to form the internal jugular vein.

The Reflections of the Dura Mater. The reflections of the dura which form the diaphragma sellæ and the cavernous sinuses have already been described. The *tentorium cerebelli* is a horizontal membrane dividing the cavity of the posterior fossa into that part occupied by the cerebellum which lies below the tentorium, and the part occupied by the cerebral hemispheres which are situated above the tentorium. It is adherent anteriorly to the superior border of the petrosa, and at its anterior end is attached to the *posterior clinoid processes*. It is directed somewhat downward, is firm and inelastic. Its circumference is attached to the posterior inferior angles of the parietal bones and to the horizontal limb of the internal occipital crest. At its attachment to the superior border of the temporal bone it contains the superior petrosal sinus, and at its attachment to the parietal and occipital bones it contains the lateral sinuses. In its center it presents a space called the *incisura tentorii*, which encircles the *mesencephalon*. The free edges of the incisura are directed forward, cross the attached anterior edge of the tentorium and gain an attachment to the *anterior clinoid processes*, the two limbs thus crossing and forming a triangular space through which pass the 3rd, 4th and 6th cranial nerves. Attached to its upper surface and holding it in place and on the stretch is the *falx cerebri*. The falx is a large membrane located in the sagittal plane and serving to separate the hemispheres. It arises anteriorly at the crista galli and continues backward to end at the superior surface of the tentorium. It is formed superiorly along the entire length of the vertex by a reduplication of the dura which passes downward from the vertex between the hemispheres. Its lower margin is free and lies between the hemispheres. Its vertical height increases from before backward, being greatest where it becomes continuous with the tentorium. Along its attached margin is located the *superior longitudinal sinus* which ends at the torcular by turning, in the great majority of cases, to the right to become the *right lateral sinus*. Along its inferior free margin is located the *inferior longitudinal sinus*, which ends by turning along the upper surface of the tentorium to become the *straight sinus* which turns to the left at the torcular. Another reduplication of the dura is a slight fold which arises along the inferior limb of the internal occipital crest and is lodged between the hemispheres of the cerebellum. This is the *falx cerebelli*. It arises below at the foramen magnum, and increasing slightly in width becomes continuous with the inferior surface of the tentorium.

THE BASE OF THE SKULL WITH DURA MATER REMOVED

The base of the skull presents three fossæ, an anterior, a middle and a posterior fossa.

The Anterior Fossa. The *anterior fossa* is bounded cephalically by the frontal bone and laterally by the frontal and parietal bones and the greater

wing of the sphenoid. Its floor is formed by the upper surfaces of the orbital plates of the frontal bone and the upper surface of the cribriform plate of the ethmoid bone. Caudally the floor of the anterior fossa is formed by the dorsal surface of the lesser wings of the sphenoid and the dorsal surface of the body of the sphenoid bone. In the midline is placed the *crista galli*, from the posterior border of which arises the *falx cerebri*. On either side of the crista galli are the slits for the nasal nerve, by which that branch of the ophthalmic division of the trigeminal nerve leaves the cranial cavity to enter the nasal fossa. Behind and lateral to the slit for the nasal nerve are *three rows of foramina*, through which pass the *fila olfactoria* from the olfactory mucous membrane to the olfactory bulb. The caudal limit of the anterior fossa is formed by the free edge of the lesser wings of the sphenoid and the caudal edge of the dorsal surface of the body of the sphenoid.

The Middle Fossa. The *middle fossa* is much more spacious than the anterior. It is deep laterally and hollowed out to receive the tips of the temporal lobes. It is somewhat in the form of a butterfly, and is limited cephalically by the free caudal margins of the lesser wings of the sphenoid, the caudal border of the dorsal surface of the body of the sphenoid bone, and the frontal bone. Caudally it is limited by the superior border of the petrous portion of the temporal bone. Laterally it is bounded by the anterior inferior angle of the temporal bone, the squamous portion of the temporal bone, the greater wing of the sphenoid and the posterior inferior angle of the parietal bone. The floor is formed by the greater wing of the sphenoid and the squamous and petrous portions of the temporal bone. Mesially the floor is raised above the level of the lateral portions of the fossa and is formed by the body of the sphenoid bone where the *pituitary fossa* is found. The caudal limit of the middle portion of the fossa is formed by the dorsum sellæ, which rises from the body of the sphenoid and presents at its summit two processes which diverge laterally, the *posterior clinoid processes*. The free margins of the lesser wings of the sphenoid are prolonged backward mesially to form two free processes, the *anterior clinoid processes*. Below the free margins of the lesser wings of the sphenoid is the *sphenoidal fissure* or the *anterior lacerated foramen*, through which pass the 3rd, 4th and 6th cranial nerves, the ophthalmic division of the 5th nerve, the orbital artery, the cavernous plexus of the sympathetic and the ophthalmic veins. Mesial to the base of the sphenoidal fissure, and separated from it by one of the pillars of the lesser wings of the sphenoid, is located the *optic foramen*, which transmits the optic nerve and the ophthalmic artery. The pituitary fossa is formed by the dorsal surface of the body of the sphenoid below and cephalically; laterally it is closed in by folds of dura mater which pass between the anterior, middle and posterior clinoid processes; these folds of dura mater enclose the *cavernous sinuses* and the nerves which enter the sphenoidal fissure. The caudal limit of the pituitary fossa is formed by the dorsum sellæ. The roof is formed by a reflection of the dura called the *diaphragma sellæ*, which is pierced near its center by the stalk of the pituitary gland. Emerging from the dorsal border of the cavernous sinus and severed in the

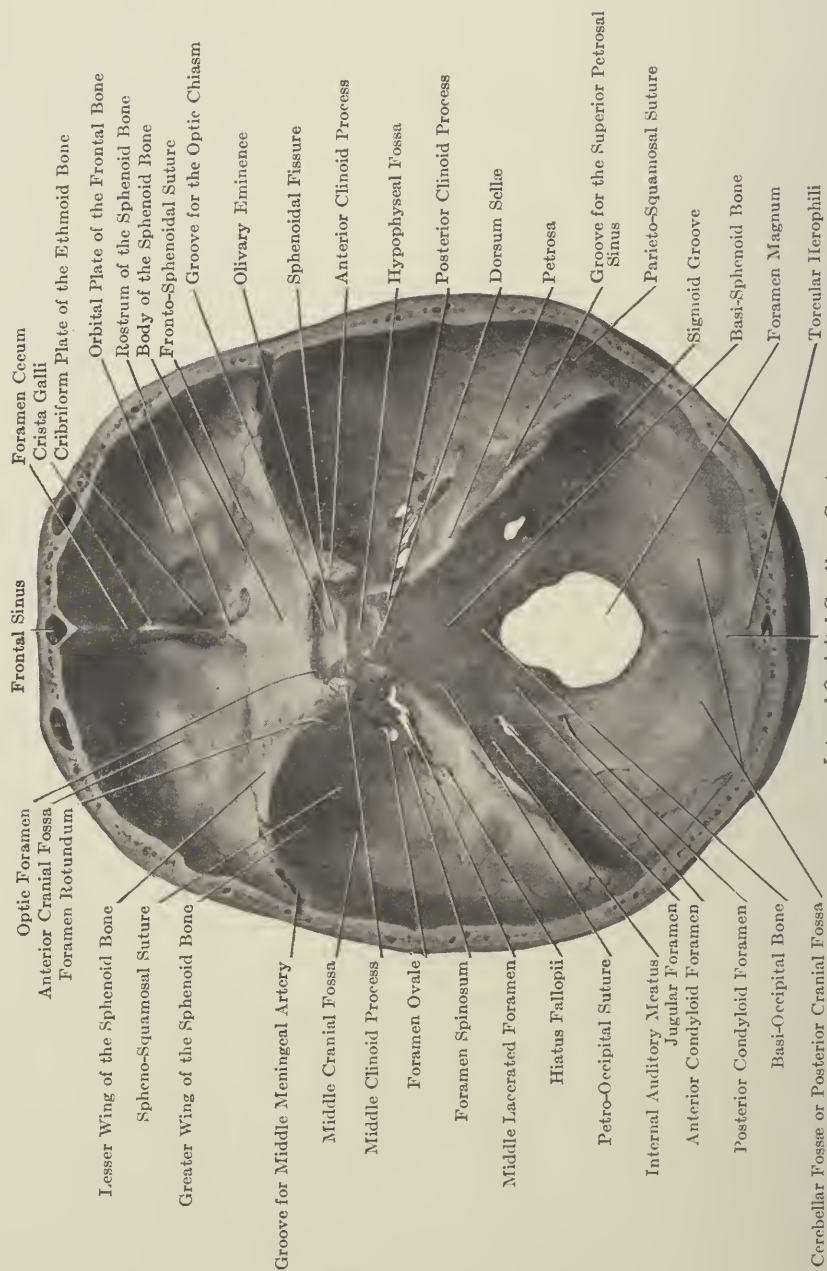


Fig. 220.—Base of the skull.

removal of the brain, will be found the stumps of the *internal carotid arteries*. The cephalic part of the median portion of the middle fossa is occupied by the *optic chiasm* which lies in front of a bony protuberance, the *olivary eminence*, which at its lateral limits presents the *middle clinoid processes*. The anterior and middle clinoid processes may unite to form a bony canal through which passes the internal carotid artery. To the caudal edge of the olivary eminence is attached the cephalic margin of the diaphragma sellæ. Below and lateral to the root of the dorsum sellæ is located the *foramen lacerum medium* which is filled in the recent state by cartilage. Through this cartilage pass the internal carotid artery and the Vidian nerve, which is made up by the great superficial and the great deep petrosal nerves. In front and to the outer side of this foramen is located the *foramen ovale*, through which pass the *mandibular division* of the 5th nerve and the *small meningeal artery*. Lateral to the foramen ovale is the *foramen spinosum*, which transmits the *middle meningeal artery*. Cephalad and mesial to the foramen ovale is the *foramen rotundum*, which transmits the *maxillary division* of the 5th nerve. The middle fossa is crossed by the spheno-parietal, the squamo-parietal, the squamo-sphenoidal and the petro-sphenoidal sutures.

On the summit of the superior border of the petrous-temporal bone close to the base of the posterior clinoid processes will be found a notch through which pass forward from the brain-stem the 3rd, 4th and 6th cranial nerves to enter the wall of the cavernous sinus. External to this notch is a shallow groove for the *dorsal root* of the 5th nerve. The dorsal root of the 5th nerve, as it penetrates the dura mater, enters a pocket between the two layers of the dura mater, the *cavum Mecklii*, in which is lodged the *Gasserian ganglion*. This ganglion lies on the tip of the petrosa of the temporal bone, and from it arise the three sensory roots of the 5th cranial nerve. Closely applied to the ganglion is the motor root of the 5th nerve. Passing dorsally and mesially from the ganglion is the *ophthalmic division* of the 5th nerve on its course forward and upward to enter the external wall of the cavernous sinus. Coursing almost directly forward to the foramen rotundum is the maxillary division, and passing outward and downward to the foramen ovale is the mandibular division of the 5th nerve.

The Posterior Fossa. The *posterior fossa* is limited cephalically by the dorsum sellæ, and the superior border of the petrous-temporal bone. Laterally and caudally it is limited by the mastoid portion of the temporal bone and the occipital bone. The floor is formed by the occipital bone, the basi-occipital and the basi-sphenoid. The posterior fossa is larger and deeper than the others and lodges the *medulla*, *pons* and the *cerebellum*. In the center of the fossa is the *foramen magnum* which transmits the neuraxis, the vertebral arteries and the spinal root of the spinal accessory nerve. On the postero-superior surface of the petrous-temporal bone is the *internal auditory meatus* which transmits the 7th and 8th cranial nerves, and between them the *pars intermedia of Wrisberg* which is the sensory root of the 7th cranial nerve. Below and behind the internal auditory meatus is the *posterior*

lacerated foramen or the *jugular foramen*, which transmits the 9th, 10th and 11th cranial nerves and the *inferior petrosal* and *lateral sinuses*. This foramen is divided into three compartments by two processes of the dura mater: the mesial compartment transmits the inferior petrosal sinus, the lateral compartment, the lateral sinus, and the middle compartment transmits the three nerves and a small meningeal branch from the ascending pharyngeal or occipital arteries. Just above the edge of the foramen magnum, lateral to its midpoint, will be found the *anterior condyloid foramina*, which are directed cephalically and laterally and transmit the 12th cranial nerves. These foramina are also called the *canales hypoglossi*.

CHAPTER XIV

THE MEDULLA OBLONGATA

ENCEPHALIZATION AND A GENERAL VIEW OF THE MEDULLA

The Prolongation of the Spinal Cord into the Head. The portion of the neuraxis protected by the vertebral column is the *spinal cord* or *myelon*, while the portion to which the skull gives protection is the *brain* or *encephalon*. The transition from vertebral column to skull is marked topographically by the upper border of the atlas. That portion of the neuraxes above this border and within the skull is the brain. In passing from vertebral column to skull there are many striking differences in form and appearance, which depend upon the development of the head. Similar differences are observed in passing from the spinal cord to the brain. These latter changes, however, are more gradual. The caudalmost portion of the brain has, therefore, much in common with the general appearance of the spinal cord. It is for this reason often called the "*prolongation of the spinal cord*," but more usually is referred to as the *medulla oblongata*. This part of the brain is also known as the *myelencephalon*, thereby denoting the region of transition in the neuraxis which presents features common to both *myelon* and *encephalon*.

The medulla oblongata, studied as a division of the human central nervous system, has proved a structure difficult to understand. Its organization seems to differ much from that of the spinal cord. Yet the fundamentals of the neuraxis seen in the spinal cord are also to be found in the medulla oblongata. They have become modified and supplemented in many ways. When, however, the reasons underlying these modifications are appreciated, the significance of the medulla is easily understood. The myelencephalon, like the myelon, is a segmented structure. But being a segmental portion of the neuraxis, why have its segments become so profoundly altered? This question leads back into the ancient history of the vertebrates. It is involved in the record of those advances in animal life which have eventuated in the development of the head.

Influences Determining the Formation of the Head. Long before the age of vertebrates, influences which determined the formation of the head were at work. The oldest part of the head is the mouth; its chief primitive activity was the capture and introduction of food into the body. Even anemones and corals have well-defined mouths surrounded by sensory tentacles which aid in procuring food. The mouth, of necessity, became the point of approach which guided the animal to food supply. It thus determined the direction of locomotion, and in this manner laid the foundation for the extensive superstructure ultimately developed at the cephalic extremity of the animal. This process which resulted in the formation of the

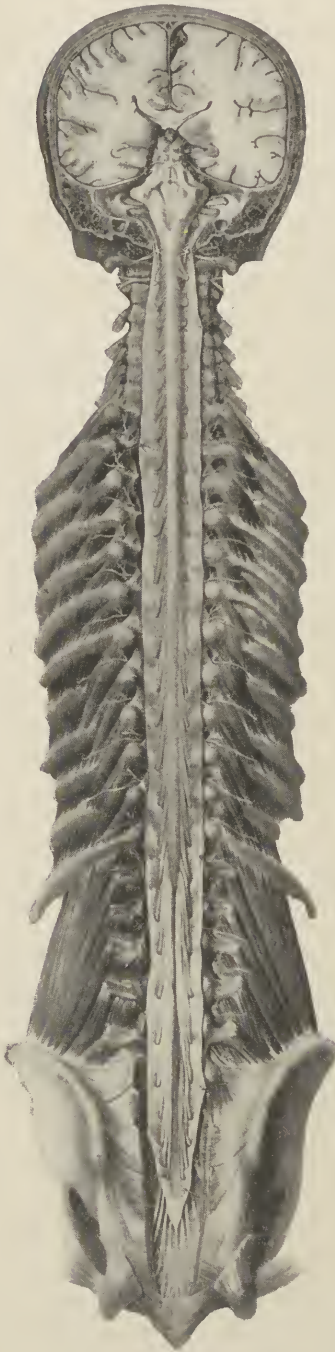


FIG. 221.—Dissection showing the spinal cord and some of the prominent changes in passing upward into the brain, especially in the "prolongation of the spinal cord," the medulla oblongata. (*Bourger*.)

head is known as cephalization. It received its initial impetus through the effects of directing animal motion, and rapidly began to expand its field of influence by the accession of organs whose purpose was the more effectual guidance of locomotion.

The addition to the head of primitive visual organs, such as those seen in the flat worms, was a distinct gain in directing motion. The concentration of certain nervous elements to form primitive gustatory and olfactory apparatus, as well as highly specialized tactile organs, the tentacles, brought new accretions of power to the cephalic region. The head became the chief guide of action in the lower forms, in which it foreshadowed the ultimate dominant control of the brain over the activities of the higher animals.

Influences Producing Modifications in the Head. Food supply in the primitive race for life is never a gratuity, and no principle has been more availing to secure existence and stimulate progress than the law of might. The head, therefore, developed as an efficient instrument of attack, and was at the same time well provided for the defense of the delicate organs which it contained. The mouth came to be surrounded by bony jaws equipped with teeth, and the head was incased in a tough skin or covered with armor-like scales for protection.

The vertebrates in their beginning showed this specialization for offense and defense in a high degree. Certain ancient fish-like animals of the Silurian and Devonian ages had a head covered by bony skin which served as a helmet.

Among the lower vertebrates, the sharks present all of the familiar features of the head, including the mouth surrounded by jaws which have a formidable equipment of teeth, the tongue and the lips, the nostrils and the well protected eye-balls. How much these advantages of the animal's head have added to the



FIG. 222.—Dissection showing some of the conspicuous differences in passing from the vertebral column to the skull. The marked differences between the spinal cord and brain are also seen. (*Bourgery.*)

effectiveness of seeking and capturing its prey, as well as providing defense against its natural enemies, is obvious at a glance.

The Requirements of Respiration—The Gills. As distance receptors, the eyes, taste-buds and olfactory organs serve as the essential directors of motion, both in pursuit and flight. In the fish, however, the head has assumed several other responsibilities. One of these activities is connected with the mouth. Primarily serving for the intake of food, the mouth also

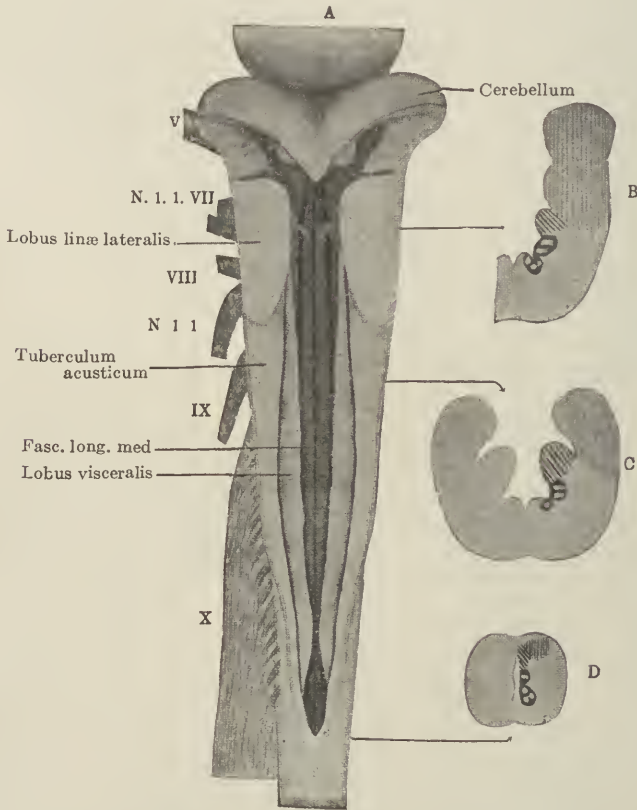


FIG. 223.—The medulla oblongata and cerebellum of the lake sturgeon (*Acipenser rubicundus*) to show the longitudinal columns which have been differentiated in correlation with the peripheral functional systems.

A is a dorsal view with the membranous roof of the fourth ventricle removed to show the longitudinal columns within the ventricle. B, C, and D are sketches of cross sections at the levels indicated in which the four functional columns are diagrammatically shaded, the somatic motor by white circles, the visceral motor by white rectangles, the visceral sensory by oblique cross-hatching, and the somatic sensory by vertical cross-hatching. The Roman numerals refer to the cranial nerves. (From Johnston's *Nervous System of Vertebrates*.)

became implicated in the function of respiration. This new function was intimately associated with the development of certain aërating organs, the *gills*. These structures consist of a set of vascular fringes situated upon either side of the head in connection with the mouth cavity. Their arrangement permits the water to circulate freely about the vascular fringes which constitute an aërating apparatus. In this manner, oxygen is taken up by the blood from the water. The gill apparatus, in addition to this provision which

it makes for the respiratory necessities of the animal, presents peculiarities in form which are equally notable. Like the body segments, the gills are arranged as a series of similar structures which vary in number from five to seven and consist of gill arches with gill clefts between them. Appended to each arch is a highly vascular gill fringe. This regular series of structures in the head region, serving the purposes of respiration, is derived from the *branchiomeres* or gill segments. They differ in respect to their origin from the body segments, which arise from the *metameres*. In the same manner that the metameres have made a deep impress upon the spinal cord, so the segments which developed in the head region in relation to the gill arches have made a correspondingly deep imprint upon the medulla oblongata.

Encephalomeres and Myelomeres. It is not surprising that the type of segmentation should differ in the spinal cord and the brain-stem. McClure has made a nominal distinction between these types by terming the segments of the spinal cord *myelomeres* and those of the brain-stem *encephalomeres*. The ex-

planation of the chief differences between these two varieties of neural segments is found in the two types of segmentation which impress themselves upon the central axis. The *metameres* (body segments) are a regular succession of equivalent segments in the region of the spinal cord. The wholly different and yet meristic series of *branchiomeres* (gill segments) is dominant in determining the form of the medulla oblongata. The major segmental influence upon the brain-stem is derived from branchiomeristic segmentation. The effects of metameric segmentation, although overshadowed by the gill arches, may be discerned to some extent in the medulla. While the encephalomeres are a series of equivalent structures, they do not present any exact equivalency with the myelomeres. The encephalomere in the medulla at least, is morphologically and physiologically different from the myelomere. It takes its chief importance from the rôle it plays in control of the gill apparatus. Its function is most intimately connected with the regulation of respiration and is, therefore, essentially *splanchnic*. The functions of the myelomeres are more especially *somatic*.

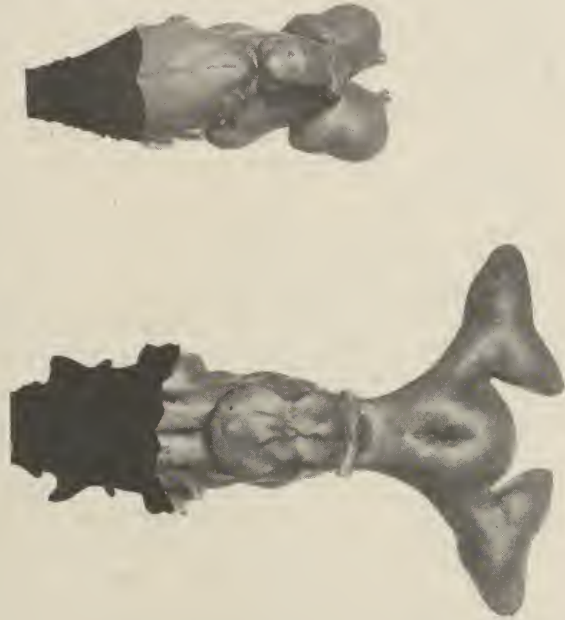


FIG. 224.—Diagrammatic representation of the myelencephalon (medulla) in the vertebrate series, ventral view. Darkened area.

Petromyzon (lamprey) above. Scyllium canicula (dog-fish) below.

Control of the Medulla Over Respiration, Cardiac Action and Gastro-Intestinal Activity. From the association of the gill mechanism with the process of aëration of the blood, it may be assumed that the chief organ of circulation would be situated in close relation with these arches. It is for this reason that in all of the fish, and in all animals depending upon gills for the aëration of the blood, the heart is situated in close proximity to the gills themselves. The distinct autonomy of the myelomere over its corresponding body segment has already been discussed. It has been seen that the principal office of such a segment of the nervous system is the control of somatic activity. The major control of the encephalomere, particularly in the region of the medulla oblongata, is concerned in the regulation of

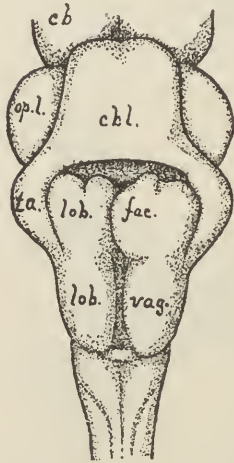


FIG. 225.—The brain of the catfish as seen from above. (Herrick.)

Lob. fac.—lobus facialis;
ta—tuberculum acusticum;
lob. vag.—lobi vagi;
cbl—cerebellum; *op. l.*—optic lobes; *cb*—cerebrum.

those receptors and effectors which cooperate in the process of aëration of the blood. This is a *visceral or splanchnic activity*. The encephalomeres of the medulla oblongata control the activity of the heart in relation to aëration of the blood and general systemic circulation. The influence of this early responsibility of the medulla in regulating respiration and controlling circulation has been transmitted through the entire line of vertebrates. It is present in those forms which came after lungs had replaced gills and the aquatic mode of life had yielded in favor of air breathing and other terrestrial habits.

The primitive relations of the mouth as an aperture for the intake of food and for aërating the blood have determined a close association between the cardio-vascular, alimentary and respiratory systems. This relationship is reflected in the influence which the medulla oblongata has continued to exert over these three systems. The control of deglutition and gastro-intestinal activities, respiration and cardiac action, has come to be an autonomy vested in the medulla oblongata.

From this fact the organ takes its chief importance in the regulation of life, and has gained its reputation as the "*nœud vital*" (vital node).

The Necessary Increase of Gray Matter in the Medulla. The requirements for the regulation of these vital processes have imposed upon the medulla certain modifications of form for which there are no analogues in the spinal cord. Because it is a portion of the nervous system which holds such autonomous control, it has, of necessity, developed more particularly along the line of its gray matter, the active substance. The result of this development is seen in the enlargement of the medulla oblongata as a whole when compared with the spinal cord. It is further evidenced by the appearance of the fourth ventricle, which has permitted the expansion of the central gray matter. The fourth ventricle is a chamber resulting from the failure of fusion of the two alar laminæ. The central gray matter in this way acquires greater proportions than in the spinal cord.

In some of the fish, this ventricle is not only an extensive cavity but also presents upon its floor a series of longitudinal columns or lobes of gray matter. The most prominent of these lobes is the *lobus visceralis*, which controls respiration and cardiac activity. It also has a gustatory function. The *lobus lineæ lateralis* and the *lobus somaticus* act in the direction of motion and the regulation of body balance.

The Development of the Fourth Ventricle. The primitive central canal of the spinal cord is entirely surrounded by gray matter. In the medulla it becomes dilated to form the fourth ventricle. In the earliest phase of development, the central nervous system presents itself as a slightly differentiated neural plate. Subsequently the neural groove is formed by the

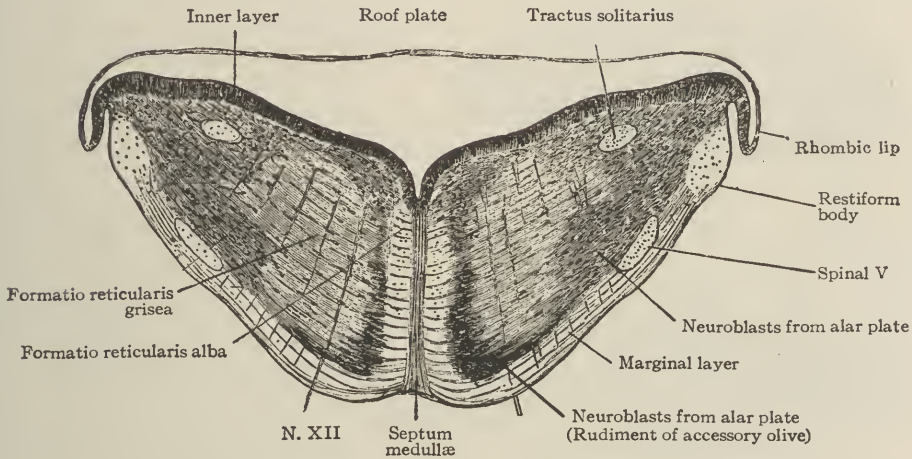


FIG. 226.—Transverse section through the medulla of an eight week's human embryo. (*His.*)

appearance of the two neural folds. These folds rising gradually, ultimately fuse in the mid-dorsal line, thus giving rise to the neural tube which encloses a large central cavity, the neural canal. This canal is surrounded by the central gray matter. As development proceeds, the gray matter in the spinal cord is enveloped by a medullary velum consisting of neuraxones, the beginning of the white matter. In the medulla, however, there is no disposition on the part of the medullary substance to envelop the central gray matter. The extreme development of the central gray matter seems to preclude such envelopment by white substance. For this reason the central canal remains open and thus facilitates the expansion of the central gray substance.

The Development of the Gustatory Sense. The medulla oblongata, through another important function, serves to increase the animal's efficiency in the search and collection of food. This object is accomplished by the aid of the gustatory or taste sense. In many fish, taste-buds are distributed throughout the mouth and along the gills and head. Some of the bony fish are still more extensively equipped with these organs, which are richly distributed over the fins and body.

The Development of the Equilibratory Mechanism. In addition to this visceral regulation, the medulla oblongata has assumed certain functions concerned in maintaining the balance of the body. These balancing activities, particularly in aquatic animals, are constantly in demand. The case is different with terrestrial animals, whose requirements in balancing are more transitory and irregular. The fish, because of its continuous needs in equilibrium, requires a more extensive mechanism for this purpose. It lives in a fluid medium and must constantly maintain its body in a certain position. No such uninterrupted demand is made upon terrestrial animals. Their medium is not only more stable, but also furnishes firm support for the body.



FIG. 227.—Diagrammatic representation of the myelencephalon (medulla) in the vertebrate series, ventral view. Darkened area.

Salmo salar (salmon) above. *Rana esculenta* (frog) below.

In the fish, provision for a balancing apparatus is made in two special sets of organs whose central control is vested in the medulla oblongata. The first set consists of a series of *semicircular canals* situated in the head. These canals are so arranged as to act as water levels for the three planes of space. The semicircular canals seem to regulate *dynamic equilibrium* while the animal is in motion. Ancillary portions of this apparatus, the *utricle* and *sacculle*, serve the purposes of *static equilibrium* while the animal is at rest.

The second set of structures in the balancing mechanism comprises the *lateral line organs* or the *neuromast system*. This system consists of a collection of specialized receptors situated upon the head in supra-orbital, infra-orbital and hyomandibular rows. It is also arranged in a line along the sides of the body extending from the head to the tail, and occupying a position midway between the dorsal and ventral fins.

These two sets of balancing organs provide for the static and dynamic equilibrium of the body. They furnish a balancing mechanism governing the movements of locomotion and rest.

The Development of Special Organs of Offense. A further tendency for specialization in the medulla oblongata is seen in the electric lobe which develops in certain fish. This electric organ consists of a large collection of nerve cells connected with specialized effectors upon the surface of the body. The electric lobe serves the animal in overcoming its quarry. It generates an electric force sufficient to stun or momentarily to paralyze

its prey. Such an organ is found in the medulla of one of the Selachians, the *torpedo*.

The Primitive Functions of the Medulla. The primitive function of the medulla oblongata is the control of those visceral activities necessary to maintain life. The manner in which the medulla came to be the dominant regulator of respiration, cardiac action, deglutition and digestion, seems clear. All of these functions are closely related and their organs intimately connected. The proximity of the gills to the heart, of the mouth to the pharynx and stomach, bespeaks a close functional association indicative of the autonomy in the medulla which dominates the vital processes. These functions have been supplemented by others which made possible the most precise direction of body movements, and in some instances have provided a mechanism, such as the electric organ, to facilitate the capture of prey.

Modifications due to the Assumption of Terrestrial Life. **AIR BREATHING.** During the critical epoch when vertebrate development led to the transition from aquatic life to terrestrial habitat, a decisive change in environment produced far-reaching effects upon all parts of the body. These changes have been especially reflected in the medulla oblongata.

Air instead of water now served as the medium to bring oxygen to the blood and the type of respiration was profoundly altered. The mechanism of the gills, which provided for respiration in water, was no longer adequate to the demands of air breathing. After many progressive modifications the structures necessary for the development of the pulmonic system finally made their appearance. In producing these changes, what was old has been made use of in the new. The central nervous system in particular has adhered to its ancient lines. In the terrestrial animal the medulla oblongata still preserves its regulating influence over the new order of respiratory mechanism. It also maintains its dominant control of cardiac functions and gastro-intestinal action.

Recession of the taste-buds and lateral line organs. The disappearance of the taste-buds from the head, from the gill arches and from the surface of the body decreased the importance of the lobus visceralis, which became reduced in size. Upon the assumption of terrestrial habits, the lateral line organs ceased to be of service, since the medium on which they depended no longer surrounded the body. This change eventually led to the disappearance of the lateral line system, which, however, was replaced by a new set of receptors sensitive to the stimuli of sound. By gradual transition the open *pit canal organ* of the lateral line came to be differentiated as

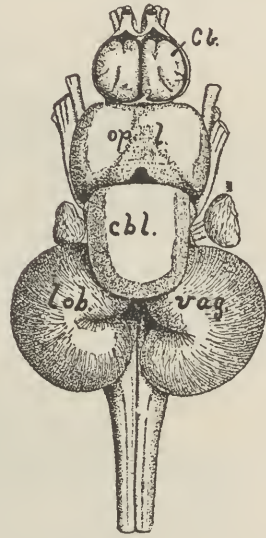


FIG. 228.—Brain of the carp as seen from above. (Herrick.)

Lob. vag—lobi vagi; *cbl*—cerebellum; *op. l*—optic lobes; *cl*—cerebrum.

the ear, which furnished if not a wholly new sense mechanism, one at least profoundly modified and susceptible to the stimuli of rapid air waves. The vestibular mechanism, in consequence of this modification, received a new element in air-breathing animals. The ear eventually assumed a dual function, *i.e.*, the ancient one handed down from aquatic life and dependent upon the semicircular canals, the utricle and saccule; and a second function probably arising out of the highly modified lateral line system which gave rise to the cochlea and made possible the sense of hearing.

PHONATION AND THE DEVELOPMENT OF THE LARYNX. It is probable that no circumstance in the evolutionary process reveals more directly the results of cause and effect than the development of phonation in response

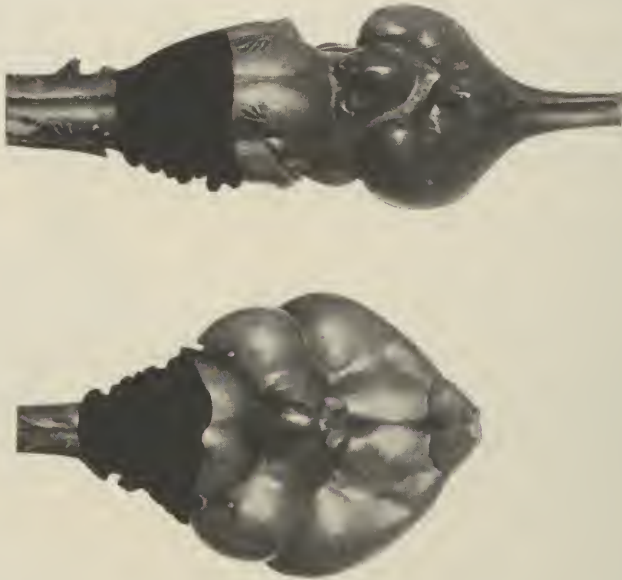


FIG. 229.—Diagrammatic representation of the myelencephalon (medulla) in the vertebrate series, ventral view. Darkened area.

Alligator mississippiensis (alligator) above. Columba (pigeon) below.

to the appearance of the organ of hearing. The auditory sense provided the animal with new information regarding its environment. It also made possible a means of communication which much increased the range of herd activities and ultimately enriched racial experience by the addition of one of the most effective instruments in social relations, the voice. Without the sense of hearing, the voice would have no reason for being. This is well shown in those born deaf, for in deaf mutes the development of the voice is either negligible or abnormal.

At the time when the lungs first made their appearance, they developed as an offshoot from the gastro-intestinal canal. Because of this relation, food and air have a common passageway for some distance from the mouth. At a certain point, however, a critical selection became necessary whereby the food should follow its own course and the air enter passages especially

designed for it. There could be no intermingling of these two elements, the food and the air, at this critical point. In response to this need, a sensitive mechanism composed of a set of delicate valves was established at the junction of the food and air canals.

The lungs especially required protection against the entrance of food, and out of this need arose the glottis, the epiglottis, and the larynx with its highly specialized vocal cords. The intimate relation between the lungs and the gastro-intestinal tract accounts for the control which the medulla has over both systems. It is but a natural consequence that this part of the brain should also regulate the mechanism which has guarded the entry into the lung and eventually developed into the organ of voice.

THE DEVELOPMENT OF THE MOBILE HEAD AND TONGUE.

Another decisive change came with the appearance of the neck and the development of the mobile head. This modification was determined in the interest of greater range in directing movements of the body and extremities. The increased mobility complicated the function of balance. It introduced new planes of motion between the head and the trunk and created new demands upon the balancing mechanism. It also added much to the function of equilibrium as concerned with movements of the eyes and the head together.

The addition of the mobile, muscular tongue implicated the medulla in another function and complicated its branchiomic control by the inclusion of the myotomes of two or three body segments (lingual metameres). In this light, the segmentation of the medulla, at least in the higher vertebrates, must be complex. It is fundamentally influenced by the gill segments, but is later supplemented by the addition of at least two or three metameric segments. The encephalomere of the medulla is not, therefore, the equivalent of the myelomere. In the higher vertebrates it represents a branchial segmentation to which is added an element of metameric segmentation.

MODIFICATIONS OF THE FACE. Certain changes in the face also made their impress upon the medulla oblongata and determined the development of one of its most prominent nuclei. The face in the lower terrestrial verte-



FIG. 230.—Diagrammatic representation of the myelencephalon (medulla) in the vertebrate series, ventral view. Darkened area.

Lepus (rabbit) above. *Canis familiaris* (dog) below.

brates consists of a bony mask covered by skin, quite incapable of facial movements and devoid of facial expression. When the scaly skin is removed from the facial portion of the skull in the reptile, no facial muscles are found. This immobile and non-muscular face also occurs in birds. It is only in the mammals that the soft muscular lips and the muscular layers about the nose, eyes, ears and forehead make their appearance. Equipped with this facial musculature capable of expressing various emotions, the mammal has acquired a new instrument for adjustment to its social environment. The expression of anger serves as a warning of encroachment, as that of hatred is a warning of impending attack. These and many other emotive expressions furnish an effective equipment for social adjustments possessed only by such animals as have a muscular, mobile face.

The origin of the facial muscles is a matter of dispute. It seems probable that the facial nerve supplying these muscles had its inception in the nerve fibers which originally supplied the platysma muscles on the surface of the throat, as well as the immediately underlying sphincter colli muscle. This sheaf of subcutaneous muscle has gradually shifted upward to take its place over the old bony mask of the vertebrate head beneath the skin. It has carried with it the original innervation through the facial nerve. It seems probable that these primitive muscles, situated in the region of the neck and ultimately spreading to the face, arose as part of the gill apparatus. They would in this sense be derivatives of the gill muscles which were supplied by the post-trematic branch of the 7th nerve in the fish.

The Influence of Suprasegmental Structures. Among the other influences modifying the form of the medulla must be mentioned the greater need for equilibratory control witnessed in the development of the cerebellum, and the introduction of volitional control attending the appearance and expansion of the cerebral hemispheres.

The medulla oblongata, from the beginning of vertebrate organization, has comprised a series of segments in which was vested the autonomous control of cardio-vascular, respiratory and gastro-intestinal activities. To these offices have been added the regulation of body movement in the interests of equilibrium and a special mechanism which made the auditory function possible.

The interpretation of the anatomy of the medulla will be aided by holding these facts in the foreground. The explanation of the modifications to which this organ has been subject in man must be sought in the progressive adaptations developed in consequence of special adjustments to terrestrial life.

CHAPTER XV

THE MEDULLA OBLONGATA

RELATIONS, SURFACE APPEARANCE AND ANATOMY OF THE MEDULLA

Situation, Boundaries and Relations. The medulla oblongata is situated within the cranium and forms the caudalmost portion of the brain. Upon removing the brain from the skull, the lower portion of the medulla oblongata is found engaging the foramen magnum.

The caudal boundary of the medulla is indicated by a plane passed horizontally through the lower margin of the foramen magnum, or, according to some authorities, the upper border of the atlas. The transition from spinal cord to medulla oblongata is not well defined. Indications of it may be found upon the neuraxis by distinguishing between the lowermost root fibers of the hypoglossal nerve and the most cephalic fibers of the first cervical nerve. A plane passed horizontally through the interval between these nerve fasciculi determines the lower boundary of the medulla. Another means of distinguishing this plane of transition is afforded by the lowest fasciculus of the pyramidal decussation. This line of demarcation, however, is not reliable. It is subject to much variation, since the lowest fibers of the pyramidal decussation are often obscured from view.

The upper boundary of the medulla, upon its ventral aspect, is the *bulbo-pontile sulcus*. The boundary line upon the dorsal aspect is indicated by the position of the *striæ acusticæ*. This boundary, however, being subject to much variation, is not reliable.

The medulla occupies the basilar groove of the basi-occipital portion of the occipital bone. Interposed between the bone and the ventral surface of the medulla are the dura mater and the ventral extension of the cisterna magna.

The dorsal surface of the medulla is in relation with the vallecule of the cerebellum; while its lateral surfaces are in apposition with the ventral extension of the cerebellar hemispheres.

Dimensions and Coverings of the Medulla. The medulla is about 20–24 mm. in length. Its diameters at its caudal extremity are: transverse, 12 mm.; ventro-dorsal, 9 mm. From this level its enlargement is slow at first, but ultimately, as it approaches its cephalic extremity, it begins to increase rapidly in its diameters. At the plane of the bulbo-pontile sulcus its transverse diameter is 18 mm. and its ventro-dorsal diameter, 15 mm.

The coverings of the medulla consist of (1) an inner vascular membrane, the pia mater; (2) an intermediate membrane, the arachnoid; (3) the cerebrospinal fluid contained in the subarachnoid space; (4) an outer membranous covering, the dura mater, and (5) the bony portion of the skull formed by

the basi-occipital, exoccipital and supra-occipital segments of the occipital bone.

PIA MATER. The pia mater of the medulla oblongata presents certain peculiarities. In addition to the fact that it is a closely investing vascular membrane, it also forms the *tela chorioidea inferior*. This is a combination of the ependymal layer, forming the roof of the fourth ventricle, and the pia mater. Situated above a portion of this ventricle, the roof membrane and the pia make numerous invaginations which give rise to the *chorioid plexus*. This structure is also known as the *chorioid gland*. It is active in the secretion of the cerebrospinal fluid. Most of the chorioideal invaginations occur in the immediate vicinity of the midline, where they appear as parallel, fringe-like projections. They form a median plexus which extends upward from the region of the obex to the inferior medullary velum. At the beginning of the lateral recesses, the plexus diverges in both directions laterally and gives rise to the *lateral plexus* which fills the lateral recesses. This portion of the chorioid gland system of the fourth ventricle extends along the lateral aspect of the medulla oblongata in relation with the ninth and tenth nerves, and projects into the subarachnoid space upon either side.

APERTURES OF THE FOURTH VENTRICLE. In early fetal life, the tela chorioidea is impervious. At about the fifth or sixth fetal month, it is perforated to form a median opening known as the *foramen of Magendie* or *apertura medialis ventriculi quarti*. This foramen lies immediately above the obex and between the strands of the chorioid plexus. Two other openings through the chorioid plexus appear in connection with the lateral recesses and are known as the *foramina of Luschka* (*aperturæ laterales*). These two apertures are usually present, one on either side, in the wall of the lateral recess, close to the vagus and glossopharyngeus nerves. The three openings in the tela chorioidea afford communication between the ventricular system and the subarachnoid space. The cerebrospinal fluid secreted by the chorioid glands of the lateral, third and fourth ventricles has, by this provision, a means of constant drainage, which prevents the distension of the cavities of the brain by the accumulation of cerebrospinal fluid.

ARACHNOID AND SUBARACHNOID SPACE. The covering of the medulla immediately external to the pia mater is fluid—the cerebrospinal fluid contained in a special division of the subarachnoid space. This particular division of the subarachnoid space constitutes the *cisterna magna* (*cisterna cerebello-medullaris*). It is in relation with the dorsal surface of the medulla and continuous, through the foramen magnum, with the dorsal portion of the subarachnoid space of the spinal cord.

The arachnoid passes from the dorsal aspect of the cerebellum to the dorsal surface of the medulla. The upper part of the medulla is thus completely invested by the subarachnoid cavity.

DURA MATER. The dura mater, lining the skull, differs from that of the spinal cord in the following particulars:

1. It is closely adherent to the bone and serves as a vascular membrane for the nutrition of the bony tissue.

2. It is continuous with the external periosteum of the cranial bones through the large foramina.
3. It reproduces itself in a number of important processes and partitions.
4. It forms certain large channels for the conveyance of venous blood.

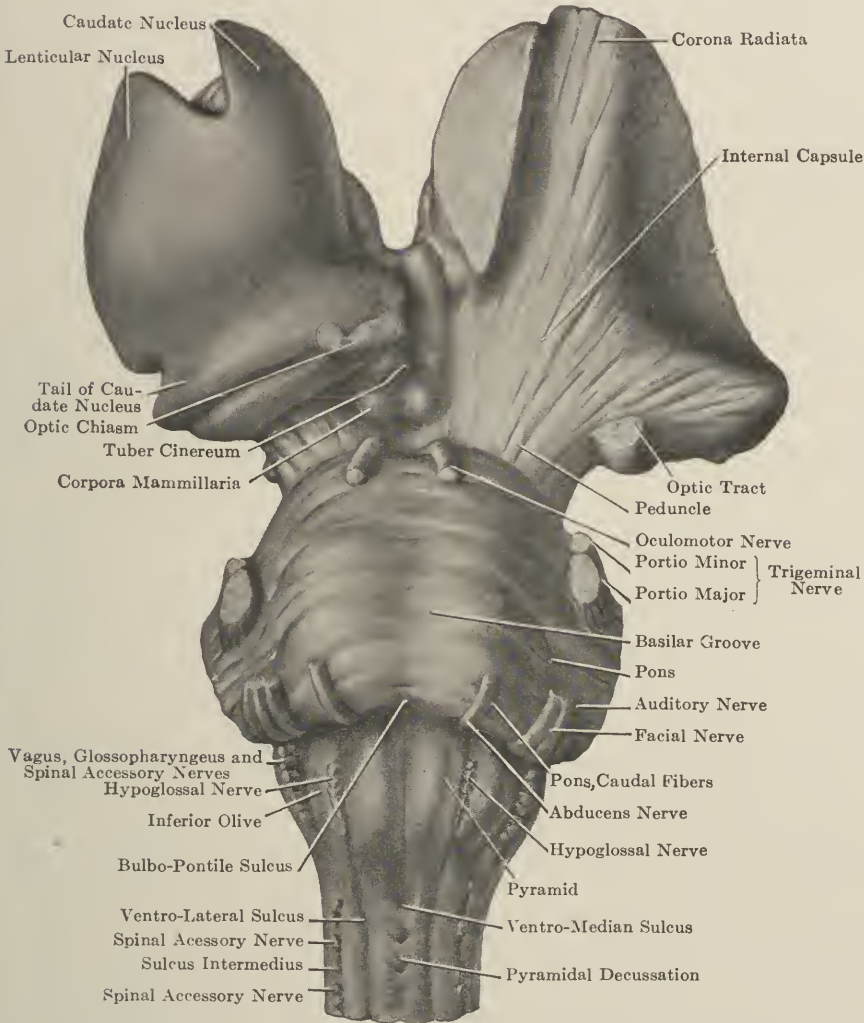


Fig. 231.—Ventral view of the neuraxis with the left internal capsule exposed.

Arteries of the Medulla Oblongata. The arterial supply of the medulla oblongata is derived from the anterior spinal, the vertebral, the basilar, and the posterior inferior cerebellar arteries. The medullary arteries are of two types. The first type consists of the *median vessels* which enter the medulla by means of the ventro-median fissure and come into immediate relation with the raphé to supply the central gray matter and adjacent nuclei. The second type consists of the *radicular vessels* which enter the

medulla in connection with the nerve roots. Upon coming into contact with the medulla, the radicular vessels break up into two branches: (1) A peripheral branch which follows the course of the nerve, and (2) a central branch which makes its way toward the various nuclei in the gray matter and to the fasciculi of the white substance.

Median branches of the anterior spinal arteries supply the nucleus of the hypoglossal nerve and the bulbar portion of the nucleus of the spinal accessory nerve.

Radicular branches from the vertebral arteries at their point of junction to form the basilar artery, supply the nuclei of the vagus, the glossopharyngeus and both divisions of the acoustic nerve.

Radicular branches of the basilar artery supply the nucleus facialis and the motor and sensory nuclei of the nervus trigeminus.

The lateral circumference of the medulla and chorioidal plexus are supplied by branches of the posterior inferior cerebellar arteries.

External Markings and Surface Features of the Medulla Oblongata. To appreciate the significance of the transition from spinal cord to medulla, it is convenient to consider certain changes observed upon each of the three aspects of the neuraxis, that is: (1) The ventral, (2) the lateral, and (3) the dorsal surface.

TRANSITION FROM THE SPINAL CORD TO THE MEDULLA AS SEEN UPON THE VENTRAL SURFACE. The first difference seen upon this surface in passing from spinal cord to medulla is the gradual increase in the transverse diameter. This diameter is 9 mm. at the upper cervical region of the cord and 18 mm. at the bulbo-pontile sulcus. This increase in diameter is indicative of large accretions in nerve substance, particularly in the amount of gray matter.

The chief features upon the ventral surface of the upper cervical segments of the spinal cord are:

1. The *ventro-median sulcus*, into which the pia mater dips to carry with it branches of the anterior spinal artery.
2. The *ventro-lateral sulcus*, which marks the point of emergence of the ventral root fibers.
3. The fairly well-defined *ventro-paramedian sulcus*, between the ventro-median and the ventro-lateral sulci.

Pyramidal Decussation. In the medulla the ventral surface presents two fairly distinct divisions, a cephalic *pyramidal portion* and a caudal *infrapyramidal portion*. Immediately after passing from the upper levels of the cord into the medulla, the first change noted is the disappearance of the ventro-median fissure. This is due to the fact that a number of interlacing and crossing bundles of fibers appear at this level and indicate the position of the *decussating pyramidal tract*. It is here that the fibers which arise in the motor cortex of the cerebral hemispheres make a more or less complete crossing, so that the right side of the brain may send impulses to the left side of the body, and vice versa.

Approximately 80 to 90 per cent of the pyramidal fibers, decussate at

this level to form the *crossed pyramidal tract*. The fibers which do not cross constitute the *direct pyramidal tract* or *fasciculus of Türk*. In rare instances, all of the fibers of the pyramidal tract make a complete decussation at this level, thus suppressing the direct pyramidal tract altogether. This arrangement is observed in many of the lower animals. On the other hand, the direct pyramidal tract, because of a scant decussation in the crossed pyramidal fibers, may appropriate as much as 90 per cent of the cortico-spinal tract. In this case the ventro-median sulcus remains a prominent feature of the ventral surface of the medulla oblongata. Usually the pyramidal decussation is symmetrical, and about an equal number of fibers cross from one side to the other. Asymmetries, however, are occasionally observed; these are due to an inequality in the pyramidal decussation. The decussating fibers follow a regular order in their crossing. Those fibers destined to supply the cord segments for the fingers, hand, forearm and arm, cross in a more cephalic position than the fibers for the shoulder girdle segments. All of the fibers for the upper extremities make a higher decussation than those for the trunk musculature and the lower extremities.

Significance of the Pyramidal Decussation According to Cajal. The reason underlying the decussation of the pyramidal tract, as well as the decussation of other tracts in the nervous system, has been a perplexing problem. For what purpose or as the result of what causes the great fiber-crossings occur in the neuraxis is not clearly understood. Cajal, however,

offers an explanation concerning decussation in general which seems as logical as it is ingenious. All decussation of tracts, according to Cajal's interpretation, depends upon the character of the vertebrate eye. The hemispherical, concave retinae with the biconvex lenses of the eyes make it essential that the optic fibers shall decussate in order that a proper mental perception of external objects may be created. Cajal believes that the crossing of the optic fibers was, in all probability, inaugurated in the fish and cephalopoda. Primitively this decussation was complete and served as the organic means of determining a mental fusion of the separate visual images received by the two eyes. The corrected visual perception could not be created without the existence of a bilateral center in the brain, each half of which cooperated with the other. The optic decussation established the proper relations between these bilateral visual centers and the two eyes. Furthermore, it exerted a decisive influence upon other pathways in the nervous system, consequent upon the reversal of the mental image in the brain. This reversal of the mental image necessitated a compensatory crossing of other tracts, especially in

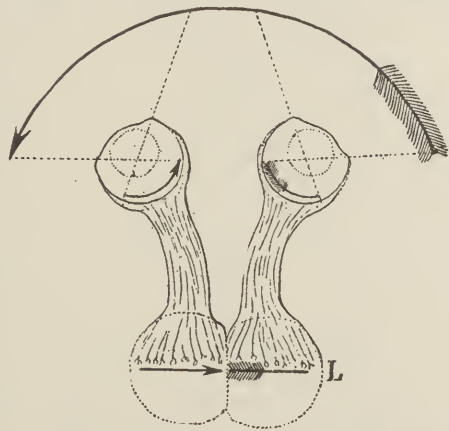


FIG. 232.—Diagram showing the distortion of the mental visual image of an object in lower vertebrates without an optic chiasm. (Cajal.)
L—Visual center.

the motor pathway. Such compensatory motor decussation in turn determined a crossing of the sensory tracts. In this manner the character of the vertebrate eye, which in the first instance enforced the complete crossing of the optic fibers, ultimately determined all decussations within the central nervous system. Cajal's conception of the visual defects resulting from failure of the optic fibers to decussate is shown in Figure 232. The compensatory effects of a complete decussation in the optic nerves upon the motor and sensory pathways are shown in Figure 233.

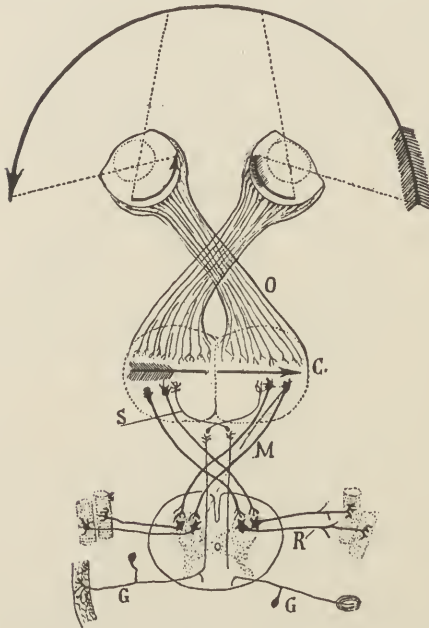


FIG. 233.—Diagram showing the usefulness of the optic chiasm and of the compensatory decussations of the motor and sensory tracts in the lower vertebrates. (Cajal.)

C—Secondary visual centers. *G*—Spinal ganglia and sensory roots. *M*—Crossed motor tract. *O*—Crossed optic nerves. *R*—Motor roots of the spinal cord. *S*—Central termination of crossed sensory tract.

Root Fibers of the Suboccipital Nerve.

Upon either side of the interlacing bundles of the pyramidal decussation is the cephalic continuation of the ventro-paramedian sulcus. Still more lateral is the ventro-lateral sulcus, from which some fibers of the first cervical nerve (suboccipital nerve) occasionally make their emergence. These ventral root fibers of the first cervical nerve are often wanting at this level. The infrapyramidal portion on the ventral surface of the medulla is thus bounded upon the two sides by the right and left ventro-lateral sulci.

The Pyramids. Passing upward along the ventral surface of the medulla into its pyramidal portion, the ventro-median fissure again reasserts itself in prominence and increased depth. The reappearance of this fissure begins about half an inch from the caudal limit of the medulla and may be traced from this point directly up to its junction with the bulbo-pontile sulcus. At this level, the ventro-median fissure forms a deep incisure between two

pronounced elevations which flank it. These elevations are the *pyramids*. They consist of two heavy strands of fibers, pyramidal in shape, with their bases resting upon the bulbo-pontile sulcus and their apices directed toward the most cephalic fibers of the pyramidal decussation. These two massive bundles, one on either side of the ventro-median fissure, represent an important link in the pathway between the cerebral motor cortex and the spinal cord. They serve to conduct volitional impulses from the brain to the body musculature. The pyramids are relatively recent accessions and reach their greatest development in the higher mammals. They are especially prominent in man and the anthropoid apes, and may be regarded as indices to the degree of volitional control which has been acquired over the movements

of the body. Their gradual attenuation in volume toward the caudal extremity of the medulla is explained by the decussation of the crossed pyramidal fibers which move out of the ventral white column to take up their typical position in the lateral white column. This position they occupy throughout the entire length of the spinal cord. The ventro-median fissure, as it comes into relation with the bulbo-pontile sulcus, presents a deep pit partially hidden by the overhanging transverse fibers of the pons Varolii; this is the *foramen cecum posterius*.

Preolivary Sulcus. Another feature of the ventral surface of the medulla is the confluence which takes place between the ventro-lateral and ventro-paramedian sulci at the junction of the upper and middle thirds of the medulla. At this level, the ventro-lateral sulcus sweeps forward to join the paramedian sulcus at the caudal extremity of the olivary eminence; thereafter the two sulci continue upward in a position lateral to the pyramids and ventral to the olivary eminence. In this relation the sulcus thus formed is known as the *preolivary sulcus*. It illustrates the disposition of the sulci in this region to be deflected ventrally as they ascend. In exceptional instances, the ventro-lateral sulcus gives rise to a few root fibers of the first cervical or suboccipital nerve. The sulcus must be regarded as the prolongation of the groove which marks the point of emergence of the ventral root fibers in the spinal cord. It is a landmark indicating the line of the ventral motor cell column.

TRANSITION FROM THE SPINAL CORD TO THE MEDULLA AS SEEN UPON THE LATERAL SURFACE. There is no distinct boundary line to distinguish the lateral surface of the medulla from the lateral surface of the spinal cord. The cephalic extremity of this surface is marked by the bulbo-pontile sulcus and the acoustic division of the 8th nerve. The ventral boundary of the lateral surface is the ventro-lateral sulcus, and its continuation the preolivary sulcus. The dorsal boundary of the lateral surface is the dorso-lateral sulcus.

Postolivary Sulcus. In general appearance, the lower two-thirds of the lateral surface does not differ from the corresponding area of the spinal cord. The cephalic third, however, shows a marked increase in the ventro-dorsal diameter, together with the appearance of several conspicuous protuberances. The most dorsal portion of this surface shows a slight indenture which brings the surface into close relation with the floor of the fourth ventricle. In actual relation with this indenture is the lateral recess of the ventricle. One sulcus of considerable morphological importance traverses

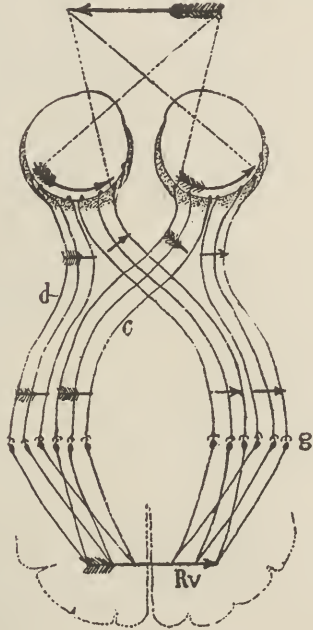


FIG. 234.—Diagram of the chiasm of the optic tracts and the central visual projection in man. (Cajal.)

c—Crossed fasciculus of the optic nerve. d—Direct fasciculus of the optic nerve. g—External geniculate body. Rv—Projection of the mental image in the visual cortex of the brain.

the lateral surface. Beginning at the caudal extremity of the medulla, the *sulcus intermedius* ascends vertically to the junction of the upper and middle thirds. Here, following the general disposition already observed in the ventro-lateral sulcus, this groove swings forward to take a position immediately

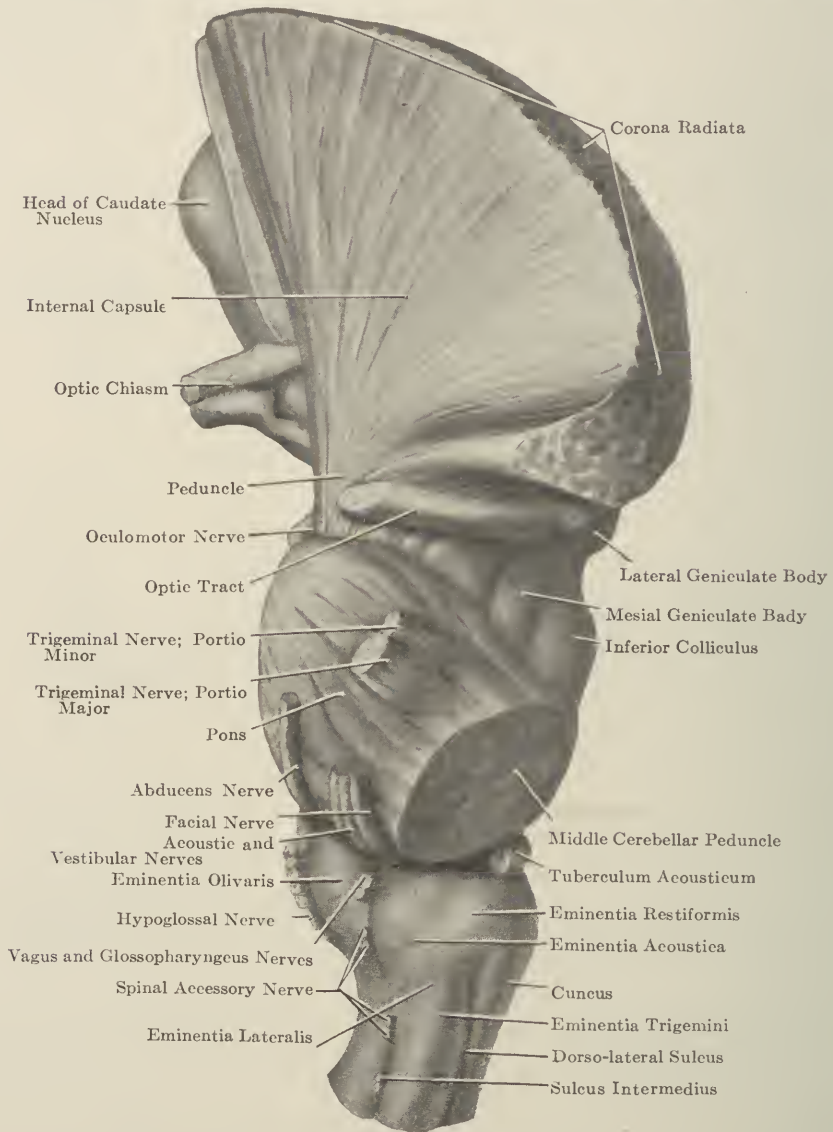


FIG. 235.—Lateral view of the neuraxis with the internal capsule exposed.

dorsal to the olivary eminence, where it is known as the *postolivary sulcus*. The importance of this sulcus is due to the fact that it marks the point of emergence of the *spinal accessory* or *11th cranial nerve*. This is a motor nerve, although its fibers select a line of emergence different from that of the ventral root fibers. Considerable significance attaches to this fact. It seems to indicate an essential difference in the type of nerves which emerge from

these two sulci. Nerve fibers making their exit from the brain-stem at the ventro-lateral sulcus supply somatic muscles. Nerve fibers escaping from the sulcus intermedius innervate muscles which have been derived in part from the gill arches. These muscles are the cephalic portions of the sterno-cleido-mastoid and the trapezius. Because they are skeletal in character but derived from branchiomeres, they are known as *branchio-motor muscles*. The nerve supplying them is a *branchio-motor nerve*. This innervation establishes a fundamental difference between the muscles supplied by fibers leaving the brain-stem through the ventro-lateral sulcus and those leaving the brain-stem through the sulcus intermedius.

The continuation of the sulcus intermedius to the position in which it forms the postolivary sulcus marks the points of emergence of two cranial nerves, the *vagus nerve* and the *glossopharyngeus nerve*. By far the larger portion of the postolivary sulcus is occupied by the emergence of the vagus nerve. The locus of emergence of these nerves indicates that their motor fibers belong to the branchial system and supply muscles derived from the branchiomeres. The postolivary sulcus also marks the site of entrance of a large group of afferent splanchnic fibers belonging to the vagus and glossopharyngeus nerves. In addition to the splanchnic sensory fibers which enter the brain-stem at the postolivary sulcus, there are also others belonging to a group of special splanchnic afferents. These fibers arise in the taste-buds of the mouth and make their way into the central nervous system through the glossopharyngeus and facial nerves.

Ventral Shift of the Dorsal Root Entrant Zone. The entrance of the splanchnic sensory fibers into the neuraxis by means of a sulcus so far forward affords a notable feature of this level of the brain-stem. There has been a slight tendency, however, for the entrant zone receiving the sensory root fibers of the upper cervical ganglia to move gradually away from its usual position in the dorso-lateral sulcus and occupy a more lateral area. This tendency has been carried to an extreme degree with the entrance of the dorsal root fibers of the vagus, glossopharyngeus and facial nerves. It has its explanation in the fact that the dorsal white column in the medulla begins to assume a character different from that found in the spinal cord. New masses of gray matter crowd into this column which make necessary the ventral shift of the dorsal root entrant zone.

Eminences on the Lateral Surface. In the caudal portion of the lateral surface, two eminences may be distinguished. The more ventral of these prominences is the *eminencia lateralis*. The direct cerebellar tract in this region is collected into a more compact bundle and produces a slight elevation upon the surface. This eminence is limited ventrally by the ventro-lateral sulcus and dorsally by the sulcus intermedius. The second prominence is the *eminencia trigemini*, also known as the *tuberculum trigemini*. This eminence makes its appearance in response to the rapidly increasing amount of substantia gelatinosa in the dorsal gray column, augmented by the large collection of fibers forming the descending root of the fifth nerve.

In the cephalic portion of the lateral surface, three distinct eminences make their appearance.

1. A large protuberance defined by the preolivary and postolivary sulci and dorsal to the pyramids, the *eminentia olivaris*. This eminence is the surface expression of a large collection of specialized gray matter situated in the medulla oblongata, the *inferior olive*.

2. Immediately dorsal to the postolivary sulcus, is a well-defined swelling, the *eminentia acustica* which extends from the bulbo-pontile sulcus for some distance caudally on the lateral surface.

3. The *eminentia restiformis* is the most dorsal of the three eminences. It is due to the progressive dorsal migration of the dorsal spino-cerebellar tract and the augmentation of this bundle by fibers from the inferior olives. The combination of these two groups of ascending fibers, one from the dorsal spino-cerebellar tract, the other from the inferior olives, constitutes the *inferior cerebellar peduncle*, which is also known as the *restiform body*.

TRANSITION FROM THE SPINAL CORD TO THE MEDULLA AS SEEN UPON THE DORSAL SURFACE. In the description of the dorsal surface of the medulla, a ventricular and an infraventricular portion may be distinguished. In man, the ventricular portion occupies less than half the dorsal surface. In many of the lower vertebrates, it occupies the entire dorsal surface. It is apparent from this fact that some of the importance attached to the formation of the ventricle has diminished in the higher vertebrates. The reduction in the amount of central gray matter may account for the relative decrease in the size of the fourth ventricle.

The infraventricular portion of the dorsal surface of the medulla has no distinct boundary line to separate it from the spinal cord. Its cephalic boundary is marked by the appearance of the fourth ventricle. The entire surface presents a gradual increase in its transverse diameter as it ascends. Upon reaching the junction of its upper and middle thirds, it begins rapidly to increase until its diameter is double that of the spinal cord.

Sulci of the Dorsal Surface. The principal sulcus of this surface is the dorso-median sulcus. It marks the position of the dorso-median septum. In the caudal two-thirds of the surface, the dorso-median sulcus is as shallow as it is in the spinal cord. Upon nearing the fourth ventricle, however, it becomes a deep cleft and is finally converted into a fissure. The dorso-lateral sulcus is discernible in the caudal two-thirds of the dorsal surface. The dorso-paramedian sulcus is present in its usual position, separating the funiculus gracilis from the funiculus cuneatus.

Eminences of the Dorsal Surface. Two protuberances make their appearance on the dorsal surface of the medulla, the *eminentia cunei* and the *eminentia clavæ*. The eminence of the clava first appears as a slight protrusion in the column of Goll in the infraventricular portion of the dorsal surface. Its caudal extremity begins at a lower level than that of the cuneate eminence. As the *eminentia clavæ* extends upward it increases in size and is separated from the second eminence of the dorsal surface by the dorso-paramedian groove. In the ventricular portion of the dorsal surface the *eminentia clavæ* comes into relation with the fourth ventricle. This eminence is referred to as the *clava*. The *eminentia cunei* is situated between the dorso-paramedian and the dorso-lateral sulci. It appears as a protuberance in the

column of Burdach and is known as the *cuneus*. Both of these eminences increase in prominence as they extend upward along the dorsal surface. They reach their greatest elevation as elements in the caudal wall of the fourth ventricle.

The *clava* and the enlarged portion of the funiculus cuneatus, called the *cuneus*, make their appearance in response to the needs of increased gray matter in order to furnish a relay in the pathway of discriminative sensibility. The fibers which ascend in the columns of Goll and Burdach,

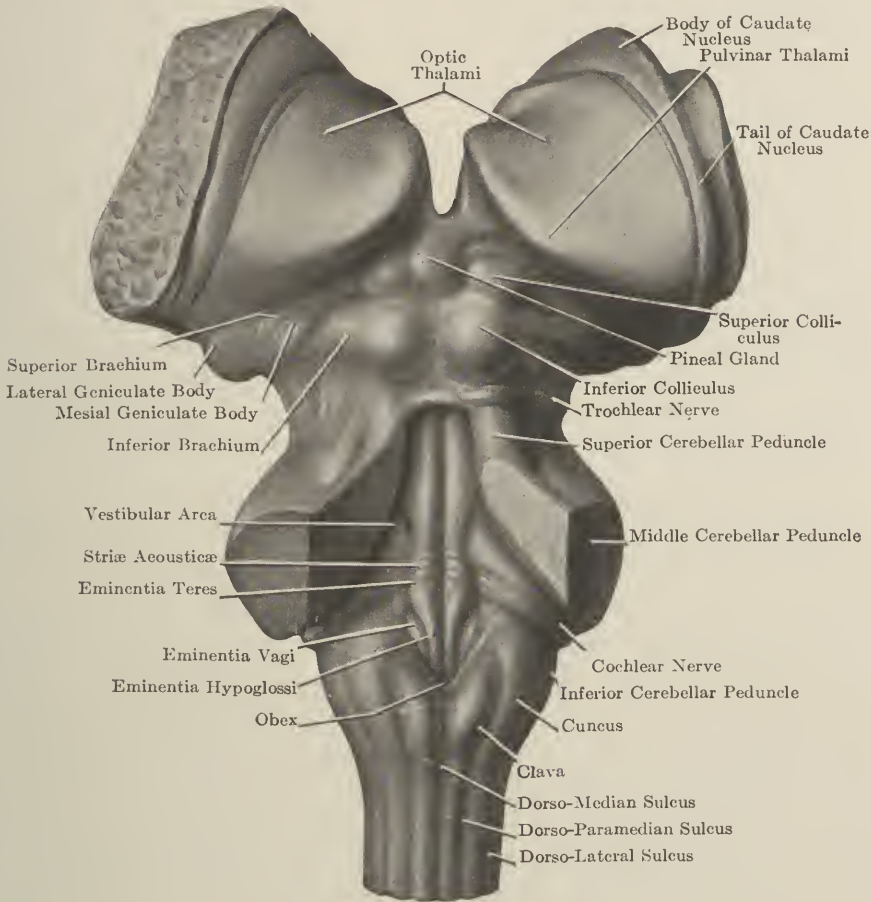


FIG. 236.—Dorsal view of the brain-stem.

at this level form synapses with cells situated in the nucleus cuneatus and the nucleus gracilis. From this relay, after undergoing decussation, the sensory pathway is continued as the fillet, whose characters will be considered in discussing the internal structure of the medulla oblongata.

Appearance of the Fourth Ventricle. In the cephalic third of the dorsal surface a marked change takes place in the relation of the two constituents composing the dorsal white columns. These columns begin to diverge from their original position in relation to the dorso-median sulcus. Their diver-

gence is symmetrical on either side, so that they form an acute angle whose axis coincides with the cephalic continuation of the dorso-median sulcus. At the apex of this angle there is a thin layer of gray matter overlying the central canal at the point where this canal begins to open into the ventricle. This process of central gray matter is the *obex*. The angle thus formed is the caudal angle of the floor of the fourth ventricle. The separation of the right and left halves of the dorsal white column exposes the floor of the fourth ventricle, the characters of which will be discussed in Chapter XX.

The appearance of this ventricle is not caused by an actual divergence of the right and left dorsal white columns. It is due to the fact that the alar plates never come into apposition, as in the case of the spinal cord. The plates remain separated in the ventricular portion of the medulla. Their convergence in the infraventricular portion results in a fusion along the mid-dorsal line and finally constitutes the tubular character of the neuraxis seen in the lower portion of the medulla oblongata and the spinal cord of man.

The boundary line which demarcates the cephalic limits of the myelencephalic portion of the fourth ventricle is an indefinite and arbitrary one. It is determined by a line passed from the lateral recess across the midline to the opposite lateral recess. This line forms the base of the caudal triangle of the fourth ventricle, which is bounded laterally by the clava and cuneus. The walls of the caudal triangle gradually become lower as they extend upward until they reach the level of the floor of the ventricle itself. In this region the two lateral recesses make their appearance in connection with the ventricular chamber.

Structures Appearing on the Surface of the Medulla Oblongata not seen in the Spinal Cord. From this description of the medulla oblongata, it is clear that certain structures make their appearance which are not seen in the spinal cord. The functional significance of these structures is important in the interpretation of the internal organization of the medulla oblongata.

On the ventral surface, the most conspicuous structures are the *pyramidal decussation* and the *pyramids*. The pyramids indicate an accession on the part of the brain-stem of a relatively recent pathway which connects the brain with the spinal cord and affords a means of communicating volitional control to the muscles of the body. The decussation of the pyramids is indicative of the partial or complete crossing of the pyramidal tract which determines the contralateral control of one hemisphere of the brain over the muscles of the body. The significance of this crossing as interpreted by Cajal has already been given.

On the lateral surface the *eminencia lateralis* indicates the increasing prominence of the dorsal spino-cerebellar tract as it ascends on its way toward the formation of the inferior cerebellar peduncle.

The *eminencia trigemini* indicates the position of the increasing mass of nerve-cells which receive sensory impulses from the face and head, the substantia gelatinosa. Included in this eminence is the descending spinal trigeminal tract which conveys sensory impulses from the Gasserian ganglion.

The *eminencia olivaris* is the largest eminence of the lateral surface.

It indicates the position of the inferior olive and is important functionally because of its probable relation to the coordination of head and eye movements.

The *restiform body* is a continuation of the lateral eminence with accretions of fibers received from the inferior olives, the combined collection forming the inferior cerebellar peduncle. This is the main pathway from the muscles to the cerebellum, and constitutes the afferent portion of the reflex arc which utilizes the cerebellum as its special center for synergic control of muscular activity.

The *eminentia acustica* is a prominent protuberance at the cephalic extremity of the lateral surface, and takes its significance from the fact that it marks the primary receiving center for nerve fibers coming in from the *spiral ganglion* situated in the internal ear. This receiving center serves the purpose of conveying auditory impulses to the brain.

On the dorsal surface the chief feature is the fourth ventricle, the significance of which in connection with the expansion of the central gray matter has already been discussed.

The *eminentia clavae* and *eminentia cunei* mark the cellular increase in the gray matter of the dorsal white columns, due to the appearance of relay nuclei which serve to convey sensory impulses from the legs, trunk, arms, neck and back of the head to the brain. These tracts act almost exclusively in the interest of discriminative sensibility.

Nerves Connected with the Medulla Oblongata. Six of the cranial nerves are connected with the medulla oblongata, namely, the hypoglossal or twelfth; the spinal accessory or eleventh; the vagus or tenth; glossopharyngeus or ninth; the auditory or eighth; and the facial or seventh.

One of these, the hypoglossal nerve, belongs exclusively to the somatic motor system and supplies the muscles of the tongue with motor impulses.

Three of these nerves belong to the mixed type and contain fibers of the splanchnic motor and splanchnic sensory components. These are the vagus, the glossopharyngeus and the facial nerves.

The *vagus nerve* by its splanchnic motor component, innervates the pharynx, the larynx, the esophagus, the stomach, the small intestine, the heart, and the smooth musculature of the trachea and bronchial tree. By its splanchnic sensory component it innervates the pharynx, the larynx, the esophagus, trachea and lungs, the stomach and small intestine. It also supplies a small cutaneous branch to the auricle of the ear. This, probably, is an aberrant fasciculus associated with the trigeminus nerve. The vagus also has a small component of the special splanchnic sensory element supplying the taste-buds in the pharynx.

The *glossopharyngeus nerve*, by its splanchnic motor component, supplies the muscles of the pharynx and some of the palatal muscles; by its splanchnic sensory component it innervates the pharynx and part of the soft palate. The posterior third of the tongue is innervated by the special splanchnic sensory portion of the glossopharyngeus nerve.

The *facial nerve*, by its splanchnic motor component, innervates all the muscles of facial expression, while by its splanchnic sensory component,

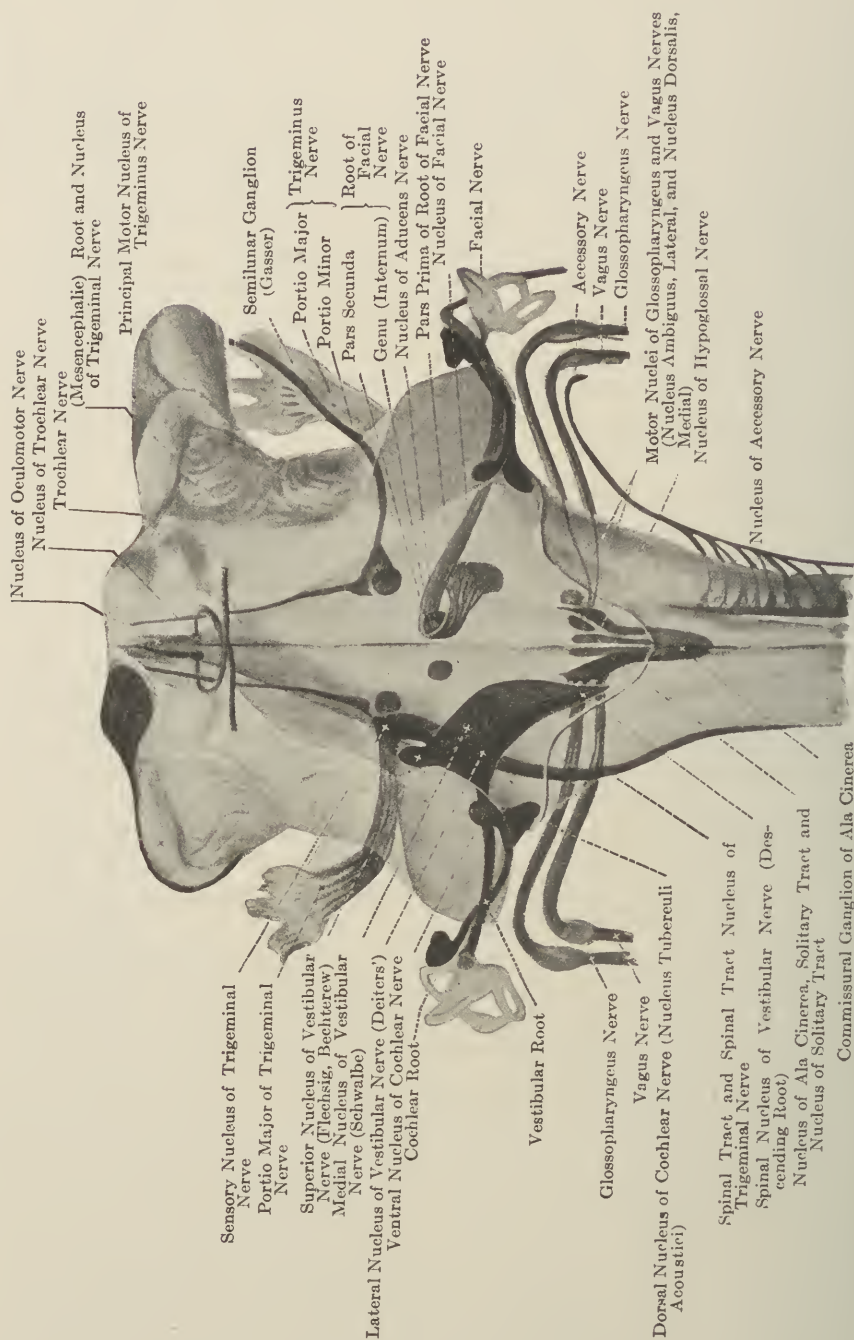


FIG. 237.—Nuclei of origin of motor, and primary terminal nuclei of sensory cerebral nerves, schematically represented in a supposedly transparent brain stem, viewed from behind. (*Spaltcholz*.)

through the *chorda tympani*, it serves as a special splanchnic sensory element for taste over the anterior two-thirds of the tongue.

One of the cranial nerves connected with the medulla oblongata is exclusively concerned with highly specialized somatic sensory impulses. This is the *auditory* or *eighth nerve* which, by means of its vestibular and acoustic divisions, mediates the transmission of impulses necessary for equilibratory control, as well as those concerned in audition.

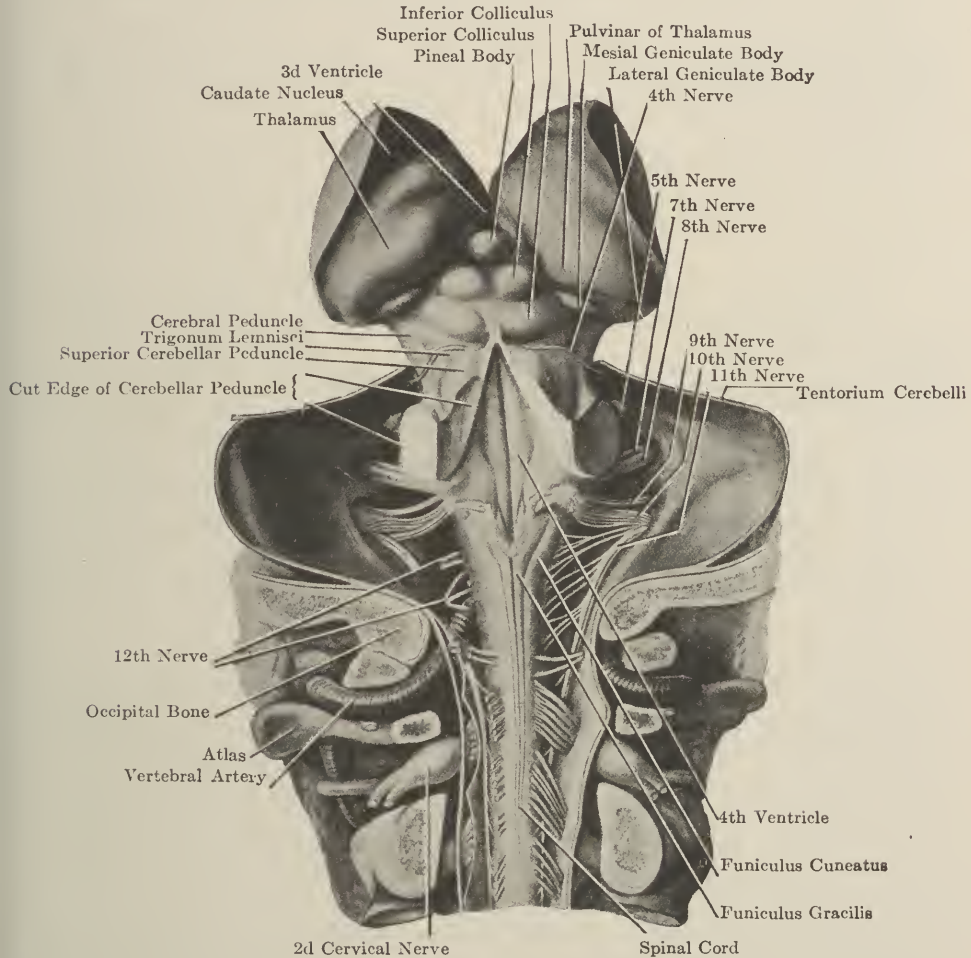


FIG. 238.—View from dorsal aspect of upper part of spinal cord, medulla oblongata, pons, fourth ventricle, mid-brain and thalamus, dissected *in situ*. (J. Symington.)

The *spinal accessory nerve* is characterized by the fact that it emerges from the brain-stem in the sulcus intermedius and supplies muscles which in part are derived from the branchial arches. It constitutes the branchio-motor supply of the trapezius and sterno-cleido-mastoid muscles.

The *hypoglossus nerve* emerges from the preolivary sulcus and is representative of the somatic motor cell column, supplying muscles derived from myotomes.

The motor portions of the facial, vagus and glossopharyngeus nerves

emerge from the postolivary sulcus and are representative of the lateral motor cell column, supplying muscles derived from branchiomeres.

The emergence of the accessory portion of the spinal accessory nerve from the sulcus intermedius may be regarded as significant of the transition in type from somatic to branchial musculature in passing from the trunk to the head. This transition might be expected in the formation of such muscles as the trapezius and sterno-cleido-mastoid, which are in part branchiomic and in part myotomic.

The Dorsal Root Ganglia of the Cranial Nerves Connected with the Medulla Oblongata. Two of the cranial nerves connected with the medulla have no dorsal root ganglia, *i.e.*, the spinal accessory and the hypoglossal nerves.

Embryologically, the hypoglossal nerve in the early stages of development has a portion of the neural crest in connection with it which, in rare instances, persists as a variant. When present, this is known as *Froriep's ganglion*.

The spinal accessory nerve in man likewise has no dorsal root ganglion, although in its early development it is in close relation with an extensive portion of the neural crest from which the root ganglia take origin.

The vagus nerve has a small dorsal root ganglion situated in the jugular foramen, known as the *ganglion jugulare*. This ganglion develops from the neural crest. In addition to this ganglionic structure, the vagus has a trunk ganglion, the *ganglion nodosum*. This is much larger, and is situated in the neck dorsal to the internal carotid artery and ventral to the superior cervical ganglion of the sympathetic. It differs from the root ganglion of the vagus in the fact that it arises from a placode of the ectoderm in connection with the fourth branchial pouch.

The glossopharyngeus nerve, like the vagus, has two ganglia. The dorsal root ganglion, the *ganglion superius*, is situated at the upper orifice of the jugular foramen; the trunk ganglion, called the *ganglion petrosum*, is situated in a small depression at the lower orifice of the jugular foramen. The ganglion superius is also known as the *ganglion of Ehrenritter* (1790), and the ganglion petrosum, bearing the name of its discoverer, is called the *ganglion of Andersch* (1791). The trunk ganglion develops from a placode in connection with the third branchial pouch, while the root ganglion takes origin from the neural crest.

The auditory nerve has a dorsal root ganglion connected with each of its two divisions. The ganglion in relation with the cochlear division is the *ganglion spirale* or *ganglion of Corti*. It is situated in the base of the lamina spiralis. The ganglion in relation with the vestibular division is the *ganglion of Scarpa*, which is situated at the external extremity of the internal auditory canal.

The facial nerve has a small dorsal root ganglion, the *ganglion geniculatum*, situated at the beginning of the facial canal in the petrosal portion of the temporal bone and immediately dorsal to the hiatus Fallopii. It serves as the root ganglion for the chorda tympani, and its dorsal root fibers constitute the *pars intermedia* of *Wrisberg*.

CHAPTER XVI

THE MEDULLA OBLONGATA

INTERNAL STRUCTURE AND HISTOLOGY OF THE MEDULLA

Rearrangements of the Gray and White Matter in the Medulla. Although the medulla oblongata consists of the same elements as the spinal cord, there is much rearrangement in its gray and white matter. These changes seem to serve several purposes. In the first place, several ascending and descending tracts take up new positions by crossing from one side to the other. Such crossings, if Cajal's explanation of decussation in the nervous system be accepted, are in the interest of adapting the neural mechanism to the optical requirements imposed by the vertebrate eye.

The second purpose of the rearrangement in the medulla affects the gray matter. Its object is to maintain an adequate control in the autonomy of its splanchnic and other special functions while adapting itself to the alterations resulting from decussations in the white matter.

These changes occur gradually and in regular order. The difference in appearance between the cross section of the upper cervical segments and the cross section of the caudal portion of the medulla is slight. The difference between the cross section of the spinal cord and that of the cephalic extremity of the medulla is so pronounced that it may be appreciated only by following the changes in serial order.

Seven critical levels of the medulla have been selected to illustrate the alterations in the relations of the gray and white matter. Before considering these changes, it is necessary to review the standard arrangement of the two chief constituents of the neuraxis as seen in the upper cervical segments of the spinal cord.

A cross section of such a spinal segment reveals the *bilateral symmetry* in the two halves of the cord with a dividing line between them indicated by the dorso-median septum and the ventro-median fissure. Each half of the section comprises in its white substance a *dorsal white column*, a *lateral white column* and a *ventral white column*. The gray matter is made up of a *ventral*, a *lateral* and a *dorsal gray column*, while the two halves of the section are connected across the midline by a *gray commissure*, or *central gray matter*, and a *white commissure*. All the changes in the medulla either depend upon alterations in the relations of these constituents or are due to the introduction of new elements. The seven critical levels selected in the medulla are:

1. The caudal limit of the pyramidal decussation.
2. The middle of the pyramidal decussation.



FIG. 239.—Section through the medulla oblongata at the caudal level of the pyramidal decussation. (Serial section No. 6.)

3. The cephalic limit of the pyramidal decussation.
4. The caudal limit of the fillet decussation.
5. The caudal limit of the inferior olive.
6. The middle of the inferior olive.
7. The summit of the inferior olive.

CHANGES IN THE GRAY AND WHITE MATTER AT THE LEVEL OF THE LOWER LIMIT OF THE PYRAMIDAL DECUSSATION. *Changes in the Gray Matter.* Upon comparing a section of the medulla oblongata at the level of the lower limit of the pyramidal decussation with the section of the upper cervical segment, certain slight changes in the gray matter are to be observed.

1. The *ventral gray column* is much smaller. It is partially cut off from the central gray substance by pyramidal fibers. These fibers are pursuing an obliquely horizontal course and making their way from the ventral white column, backward and outward, across the midline toward the contralateral white column. The ventral gray column has the appearance of an isolated collection of nerve cells. This isolation of the ventral gray column is usually more marked on one side than on the other, for the reason that nearly all of the pyramidal fibers have previously made their decussation. Those fibers which are still crossing represent the few fasciculi which have yet to enter the pyramidal decussation. There are *two distinct clusters of motor cells* in the ventral gray column; one situated ventro-mesially and the other ventro-laterally. Both clusters give rise to emergent nerve root fibers which go to make up the motor portion of the first cervical (suboccipital) nerve.

2. The *lateral gray column* has increased in size, especially near its base. It does not present so pronounced an apex as is the case in the cervical region. At its base is a crowded cluster of large motor cells constituting the *nucleus ventralis accessorius*, which gives rise to some of the accessory fibers of the eleventh cranial nerve.

3. The *reticular formation* has increased not only in size, but also in the richness of the distribution of the gray matter in it. It occupies a position bounded by the caput, body and neck of the dorsal gray column, dorsally; by the central gray matter, mesially; by the ventral gray column, ventrally; and by the lateral white column, laterally. Some of the fibers of the crossed pyramidal tract, at this level, lie in close relation to the outer margin of the reticular formation, while some of the horizontal fibers in the pyramidal decussation traverse the reticular formation on their way toward the crossed pyramidal tract.

4. The *dorsal gray column* is much increased in size and has moved laterally away from the dorso-median septum. Its caput is especially enlarged, due to the increase in the amount of substantia gelatinosa, whose volume at this level has become sufficient to produce a slight protuberance upon the lateral aspect of the medulla, the *eminentia trigemini*. The neck and body of the dorsal gray column are both shorter and thicker. Certain large nerve-cells are situated in the position of the mesial basal group, occupying an area similar to that of the posterior vesicular column of Clarke. These cells are

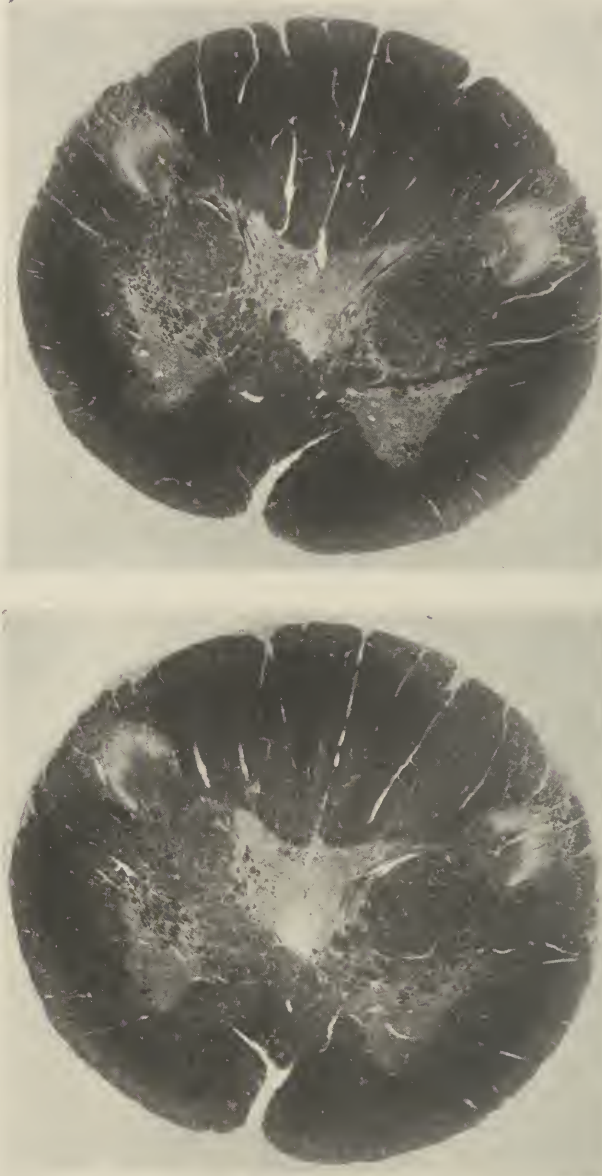


FIG. 240.—Serial sections of brain-stem Nos. 20 and 34 showing the pyramidal decussation, the detachment of the ventral gray columns from the central gray substance, the general enlargement of the latter, the increased size of the dorsal gray column, and the effect of decussation upon the ventro-median fissure of the medulla oblongata.

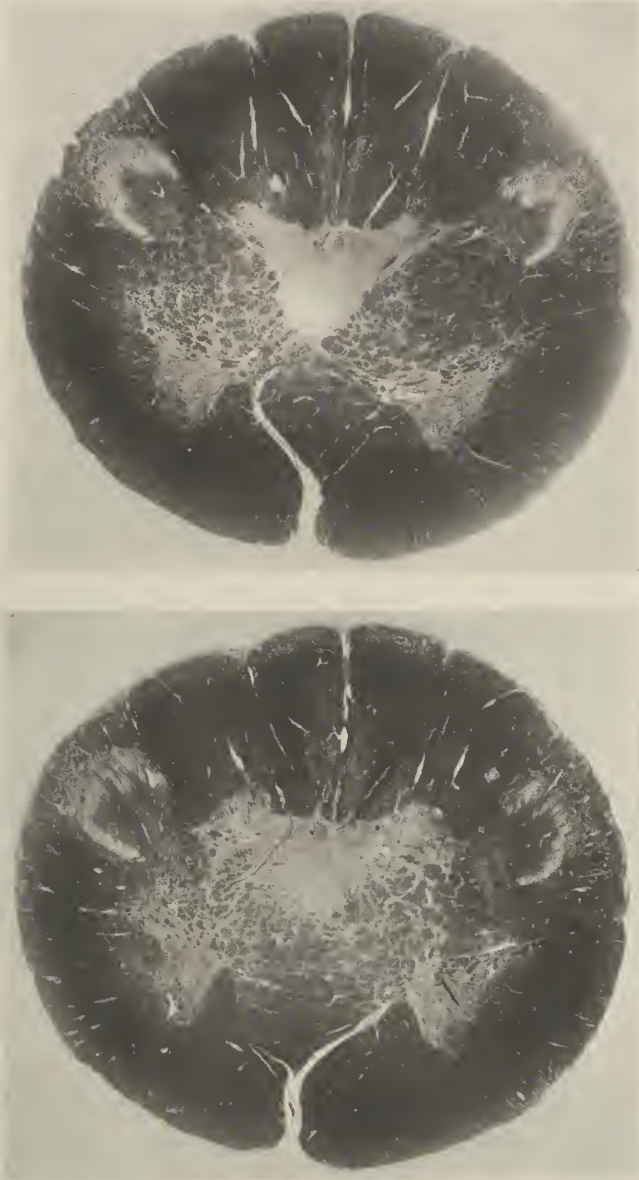


FIG. 241.—Serial sections of brain-stem Nos. 48 and 62, showing the marked effects of the pyramidal decussation upon the internal configuration of the medulla oblongata. Sections Nos. 20, 34, 48 and 62 intervene between the caudal level of the pyramidal decussation and the next more cephalic level which is labeled in detail. These intervening sections illustrate the gradual process of rearrangement in the gray and white matter.

no doubt closely related in function to those of Clarke's column. Numerous reflex collaterals from the entrance zone of the upper cervical nerve make their way across the neck and body of the dorsal gray column in the direction of the ventral gray column.

5. The *central gray matter* has also increased in size; it has the appearance of a quadrilateral structure quite dissimilar to the narrow commissural band which stretches from side to side in the cervical region. This change in the central gray matter is one of the most striking alterations observed in the gray matter at this level of the medulla oblongata. There is also a slight tendency for the central gray matter to move further dorsally, as if in process of extending toward the dorsal surface of the medulla. This dorsal migration of the central gray matter is a movement of much importance in the subsequent changes in the medulla oblongata. The central canal is centrally placed. In many instances this is a distinguishing feature of the medulla since, as a rule in adult life, the central canal in the spinal cord becomes obliterated or replaced by a cluster of ependymal cells. Ventrolateral to the central canal is a group of medium sized motor cells constituting the *nucleus dorsalis accessorii* which gives rise to emergent root fibers of the spinal accessory nerve. Along the dorsal border of the central gray matter, mesial to the collection of cells forming the mesial basal group, is a fairly large sized collection of finely medullated nerve fibers constituting the *fasciculus longitudinalis dorsalis* of Schütz. This fasciculus probably represents an ancient motor pathway in the central nervous system.

6. *No new elements* in the gray matter have made their appearance at this level.

Changes in the White Matter. 1. The *dorsal white columns* are both much more extensive in their transverse diameters. They are divided into two fasciculi, the *fasciculus gracilis*, situated mesial to the dorso-paramedian sulcus, and the *fasciculus cuneatus*, occupying a position lateral to this sulcus. The enlargement of the column is due to the addition of many ascending fibers to the tracts of Goll and Burdach. Some axones situated at the junction of the dorsal white column with the dorsal gray column indicate the entrance of dorsal root fibers of the first cervical nerve. These fibers make up a relatively small *root entrance zone*. 2. The *lateral white column* presents the circumferential, intermediate and juxtagriseal zones.

In the circumferential zone, the *tract of Lissauer* is much reduced in size and occupies the most dorsal position. Immediately ventral to it is a relatively large fasciculus of descending fibers which constitutes the *descending* or *spinal root of the trigeminal nerve*. Numerous collaterals from this tract end in the substantia gelatinosa. Ventral to the descending root of the fifth nerve is a large bundle of fibers, the *dorsal spino-cerebellar tract* (tract of Flechsig). The *ventral spino-cerebellar tract* (tract of Gowers) occupies a position ventral to the tract of Flechsig, and a small triangular bundle, the *olivo-spinal tract* (tract of Helweg) completes the lateral circumference.

The intermediate zone contains in its most dorsal position the *crossed pyramidal tract*, ventral to which are the *rubro-spinal*, the *lateral Deitero-spinal* and the *spino-thalamic tracts*.

The juxtagriscous zone contains some of the crossed pyramidal fibers turning from their horizontal into their vertical course. It is made up in the main by the fibers entering the reticular formation.



FIG. 242.—Section through the medulla oblongata at the middle of the pyramidal decussation. (Serial section No. 95.)

The *lateral gray column* is somewhat increased in size. It contains an extension of the *nucleus ventralis accessorius* and, together with the ventral gray column, is separated from the remaining gray matter of the medulla.

The *reticular formation* is reduced in size and much obscured by the decussating pyramidal fibers.

The *ventral white column* is distinguished at this level by the pyramidal

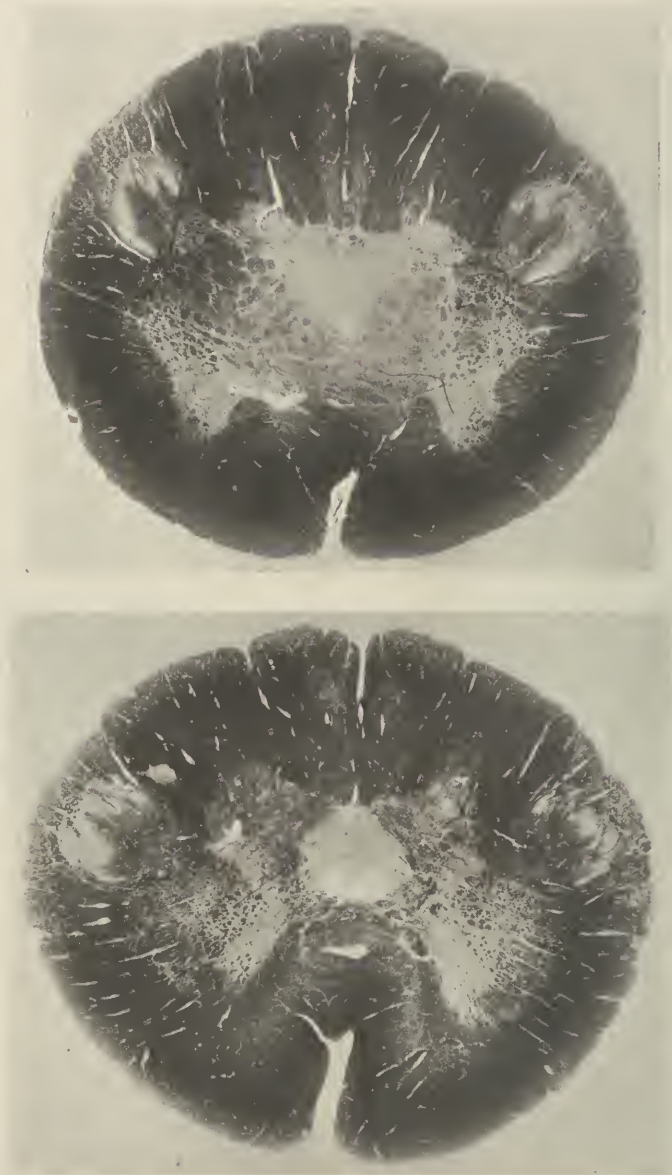


FIG. 243.—Serial sections of brain-stem Nos. 109 and 135, showing the rearrangements in the gray and white matter incident to the pyramidal decussation. These sections represent intervening levels between the middle of the pyramidal crossing and the cephalic extremity of this decussation.

fibers which make their way dorso-laterally to a position in the crossed pyramidal tract. These fibers represent the caudalmost elements in the

pyramidal decussation. There are also other pyramidal fibers which do not decussate at this level but remain uncrossed until they reach the spinal cord. These fibers constitute the *direct pyramidal tract* (fasciculus of Türk). The ventral white column contains the *ventral Deitéro-spinal* and the *tecto-spinal tracts*.

The *new elements* in the white matter at this level are the *pyramidal decussation* and the *fasciculus longitudinalis dorsalis* of Schütz, an ancient motor pathway in the neuraxis. This fasciculus is incorporated in the dorsal portion of the central gray matter.

Emergent and Entrant Root Fibers at this Level. Two groups of emergent root fibers appear at this level of the medulla oblongata. First, motor fibers arising from groups of motor cells in the ventral gray column and constituting the ventral root of the *first cervical nerve*.

The second group of emergent root fibers arise from the two nuclei of the *spinal accessory nerve*. The course of these emergent fibers is of moment and should be described in detail. The ventral root fibers of the first cervical nerve make their way forward and outward to the ventro-lateral sulcus, where they emerge in line with the other motor root fibers of the cervical, the thoracic and the spinal nerves. The emergent fibers from the two nuclei of the spinal accessory nerve sweep backward, inward and then outward until they reach a point of emergence immediately in front of the anterior margin of the dorsal gray column. Here they make their escape from the medulla in the *sulcus intermedius*. This circuitous course in emerging from its origin is a characteristic, not only of the spinal accessory nerve, but also of the cranial nerves which belong to the same system as the eleventh nerve.

A few dorsal root entrant fibers occupy the usual zone and represent the sensory elements in the suboccipital nerve. In many instances these sensory elements are entirely wanting.

Fissures and Septa. Several changes occur in the fissures and septa. Among these is the decrease in depth of the ventro-median fissure caused by the crossing pyramidal fibers. The dorso-median septum has lost the appearance of an actual septum and has become a deep fissure extending from the dorsal surface of the medulla to the dorsal surface of the gray matter. The other sulci, marking the point of entrance and emergence of the nerve roots as well as the position of the paramedian septa, correspond in all details to those in the spinal cord.

CHANGES IN THE GRAY AND WHITE MATTER THROUGH THE MIDDLE OF THE PYRAMIDAL DECUSSATION. *Changes in the Gray Matter.* 1. The *ventral gray column* has become still further reduced in size as compared with the level just described. It is now isolated from the rest of the gray matter of the medulla and surrounded by white substance. This isolation, giving the ventral gray column the appearance of an island, is brought about by the pyramidal fibers which are decussating at this level. In the ventral portion of this collection of gray matter are a few scattered cells representing motor elements of the *first cervical nerve*, while the major portion of the gray matter is occupied by a large group of motor cells constituting the *ventral accessory nucleus*.

2. The *dorsal gray column* is enlarged, due to the increase in the *substantia gelatinosa*. It has moved further away from the dorso-median fissure by reason of the increase in size of the dorsal white column. The neck and body of the dorsal gray column are shorter and thicker than in the lower level, and there is no evidence of the mesial basal group of cells representative of Clarke's column.

3. The *central gray matter* of the gray substance shows a still further enlargement and a marked tendency toward dorsal migration. It lies about midway between the ventral and dorsal surfaces. The central canal has increased in size, and the *nucleus dorsalis accessorius* is presented as a collection of cells situated at its ventro-lateral margin. On the dorsal margin of the central gray matter are the fibers which constitute the *dorsal longitudinal fasciculus* of Schütz.

4. No new elements of gray matter have made their appearance at this level of the medulla oblongata.

Changes in the White Matter. 1. The *dorsal white columns* are broad and their separation into the *fasciculus gracilis* and *fasciculus cuneatus* is more pronounced because of the increased prominence of the dorso-paramedian sulcus and septum. There is no root entrance zone and in certain respects the white matter resembles the reticular formation; this appearance is caused by the richness of the septal processes in the dorsal white column.

2. The *lateral white column* has become narrower, while the *reticular formation* is reduced in size and obscured by the massive crossing of the pyramidal fibers. The three zones are still discernible.

The *circumferential zone* is made up of its characteristic tracts, the *descending or spinal root of the trigeminal nerve*; the *dorsal spino-cerebellar tract*; the *ventral spino-cerebellar tract* and the *olivo-spinal tract* or tract of Helweg. The *tract of Lissauer* appears as a small element situated at the dorso-lateral apex of the *substantia gelatinosa*.

The *intermediate zone* is largely taken up by the decussating horizontal fibers of the pyramidal decussation, ventral to which are situated the *rubro-spinal tract*, the *lateral Deitero-spinal tract* and the *spino-thalamic tract*.

The *juxtagriseal zone* is occupied by the decussating fibers of the pyramidal tract.

3. The *ventral white column* is characterized by the *decussation of the pyramidal fibers* and also by the caudal extremity of the *pyramids* themselves. In addition to these fibers the ventral white column contains the *tecto-spinal tract* and the *ventral Deitero-spinal tract* both crossed and uncrossed.

4. Although there are no actual *additions to the white matter*, a conspicuous change is determined by the pyramidal decussation. It is by means of this decussation that the contralateral control of the cerebral cortex over the body musculature is accomplished.

Emergent Root Fibers. The only emergent root fibers at this level are those arising in the ventral and dorsal nuclei of the *spinal accessory nerve*.

Those ventral root fibers taking origin in the ventral gray column and destined to enter the suboccipital nerve, descend for a considerable distance in the reticular formation before they make their emergence from the neuraxis. There are no sensory root fibers entering the medulla at this level.

Fissures and Septa. The ventro-median fissure is almost obliterated because of the interlacing of the fibers in the pyramidal decussation. This fissure appears as a shallow cleft extending inward for a short distance and then forking, so that one branch turns to the left and the other to the right. Both of these divergent limbs of the ventro-median fissure result from the crossing fibers of the pyramidal decussation. This forked appearance of the ventro-median sulcus is seen nowhere else in the neuraxis.

The dorso-median sulcus has become a pronounced fissure extending from the dorsal surface of the medulla to the dorsal aspect of the central gray matter. In its more dorsal portion, there is some tendency for this fissure to show a still greater divergence of the white columns which bound it. This divergence eventually results in the appearance of the floor of the fourth ventricle.

CHANGES IN THE GRAY AND WHITE MATTER AT THE LEVEL OF THE CEPHALIC LIMIT OF THE PYRAMIDAL DECUSSATION. *Changes in the Gray Matter.*

1. The *ventral gray column*, almost completely isolated by the decussating fibers of the pyramidal tract, is much reduced in size. It still contains some nerve cells which give rise to fibers of the spinal accessory nerve.

2. The *lateral gray column* is slightly larger than in the lower section. It also contains a portion of the nucleus ventralis accessorii.

3. The *reticular formation* has been invaded by the crossing fibers of the pyramidal tract. It is in this manner obscured and somewhat reduced in size.

4. The *dorsal gray columns* have migrated laterally until they lie slightly dorsal to the transverse diameter of the section.

The gray matter is increased in size by still further additions to the substantia gelatinosa. The neck and body of the dorsal gray column have lost definite outline due to the appearance of other masses of gray matter.

5. The *central gray matter* shows a still further tendency toward dorsal migration, and the central canal is somewhat larger than in the lower sections. In its ventro-lateral margin, it contains the nucleus dorsalis accessorii. In its dorsal margin is the fasciculus longitudinalis dorsalis of Schütz.

New Elements in the Gray Matter. Several new masses of gray matter have made their appearance at this level and represent elements of major importance. The first of these is the *nucleus gracilis*, a collection of gray matter situated immediately adjacent to the dorso-median fissure and projecting into the column of Goll. This nucleus serves as a relay station for the fibers ascending in the fasciculus gracilis, which, by means of synapses, form a part of the pathway for discriminative sensibility. The nucleus extends from the dorsal aspect of the central gray matter to the dorsal periphery of the medulla. Immediately lateral to it is another new mass

of gray matter, the *nucleus cuneatus*. This nucleus extends from the dorsal margin of the central gray toward the periphery of the column of Burdach.

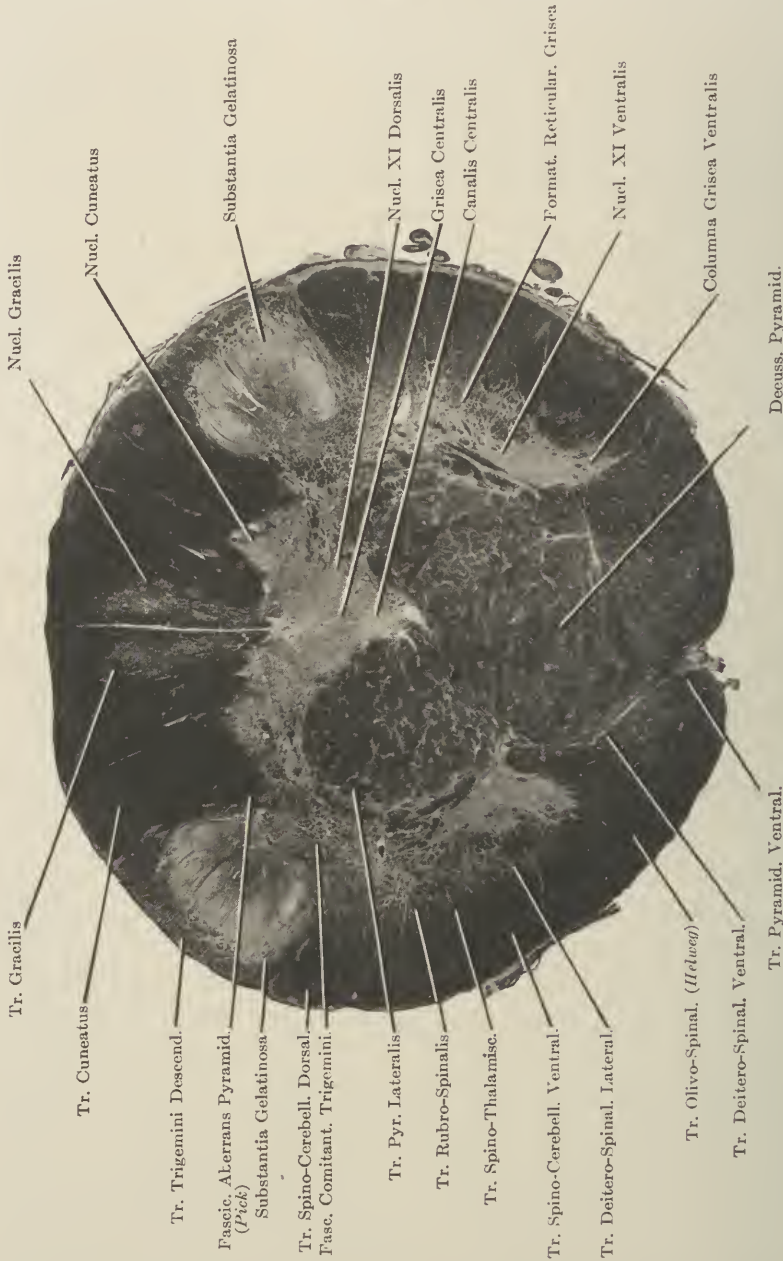
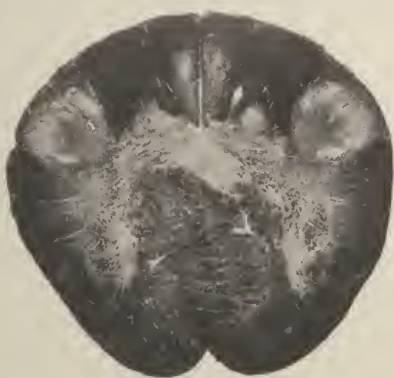


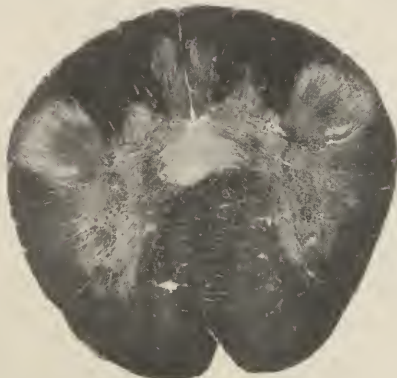
Fig. 244.—Cross section through the medulla oblongata at the cephalic level of the pyramidal decussation. (Serial section No. 175.)

The appearance of these new masses of gray matter causes changes upon the surface which have already been mentioned, the nucleus gracilis giving rise to the *eminentia clavæ*, the nucleus cuneatus giving rise to the *eminentia*

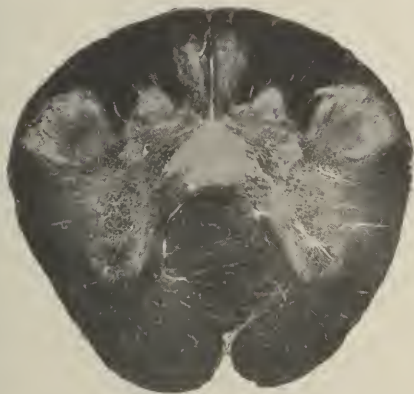
cunei. This level of the medulla oblongata contains in its more dorsal aspect groups of cells which serve to relay sensory impulses from all parts of the



Serial Section No. 189



Serial Section No. 203



Serial Section No. 213



Serial Section No. 231

FIG. 245.—Four intervening sections between the cephalic level of the pyramidal decussation and the caudal level of the fillet decussation.

body to their final sensory areas in the brain. These groups of cells are collected in three nuclei, the *nucleus gracilis*, which relays impulses received from the legs and lower trunk; the *nucleus cuneatus*, which relays impulses received from the arms, upper trunk and neck; and the nucleus contained in the *substantia gelatinosa*, which relays impulses received from the head, face and cavities of the head. A line drawn transversely through the central canal at this level would bound a region upon the dorsal aspect of the neuraxis devoted to the relay of sensory impressions coming from the entire body. For the most part, these impressions are concerned in discriminative sensibility. In the case of the head and face, however, it is probable that all types of sensibility, including pain and temperature, receive their relay in the nucleus represented by the substantia gelatinosa. In this respect, the medulla oblongata does not differ from the spinal cord, the dorsal region of which is largely concerned with the transmission of discriminative impulses.

Another new element appearing at this level is a small mass of gray matter situated dorsal to the substantia gelatinosa and surrounded by fibers of the fasciculus cuneatus. This is an *accessory portion of the substantia gelatinosa*.

Changes in the White Matter. 1. The *dorsal white column* is much smaller, as it now contains the nucleus cuneatus and nucleus gracilis which occupy some of the space formerly taken up by ascending fibers of the two dorsal tracts.

2. The *lateral white column* shows an important change in the small number of pyramidal fibers contained in the intermediate zone. The circumferential zone contains its usual elements, *i.e.*, the *descending spinal tract of the trigeminal nerve*, the *dorsal spino-cerebellar tract*, the *ventral spino-cerebellar tract* and the *olivo-cerebellar tract* (tract of Helweg). The intermediate zone still has a few fibers of the *crossed pyramidal tract*, in addition to the *rubro-spinal*, the *spino-thalamic*, and the *lateral Deitero-spinal tracts*. The juxtagriseal zone is made up of intersegmental fibers.

3. The *ventral white column* presents the beginning of the pyramidal decussation, and is the most conspicuous element in the ventral white column. The ventral Deitero-spinal and the tecto-spinal tracts also occupy positions in this column.

4. *Additions to the white matter*, comprising two groups of fibers, usually make their appearance at this level. One of these, the *fasciculi comitantes trigemini*, occupies a position immediately mesial to the substantia gelatinosa and is concerned in the transmission of sensory impulses received from the head and face. The second element is the *fasciculus pyramidalis aberrans*, or the *fasciculus of Pick*. This bundle of fibers represents a collection of pyramidal axones following an aberrant course immediately ventral to the more scattered fasciculi comitantes of the trigeminal nerve.

Emergent Root Fibers. The only emergent root fibers at this level are those of the spinal accessory nerve which make their characteristic course backward, then forward and outward to emerge from the *sulcus intermedius*, ventral to the substantia gelatinosa.

Fissures. The ventro-median fissure is shallower, due to the pyramidal decussation. The dorso-median fissure is wider and more shallow, due to the dorsal migration of the central gray matter and the appearance of the nucleus gracilis. The other sulci are similar in all respects to those previously described in connection with the lower levels of the medulla oblongata.

CHANGES IN THE GRAY AND WHITE MATTER AT THE LEVEL OF THE CAUDAL LIMIT OF THE FILLET DECUSSATION. *Changes in the Gray Matter.*

1. The *ventral gray column* at this level has disappeared, or at most consists of a few scattered groups of nerve-cells constituting the cephalic extremity of the ventral accessory nucleus of the eleventh cranial nerve.

2. The *lateral gray column* has also disappeared, with the possible exception of some scattered motor cells representing elements in the ventral accessory nucleus.

3. The *reticular formation* has again resumed its former proportions and is now divisible into a lateral gray portion, the *formatio reticularis grisea*, and a mesial portion, the *formatio reticularis alba*. In this region the reticular

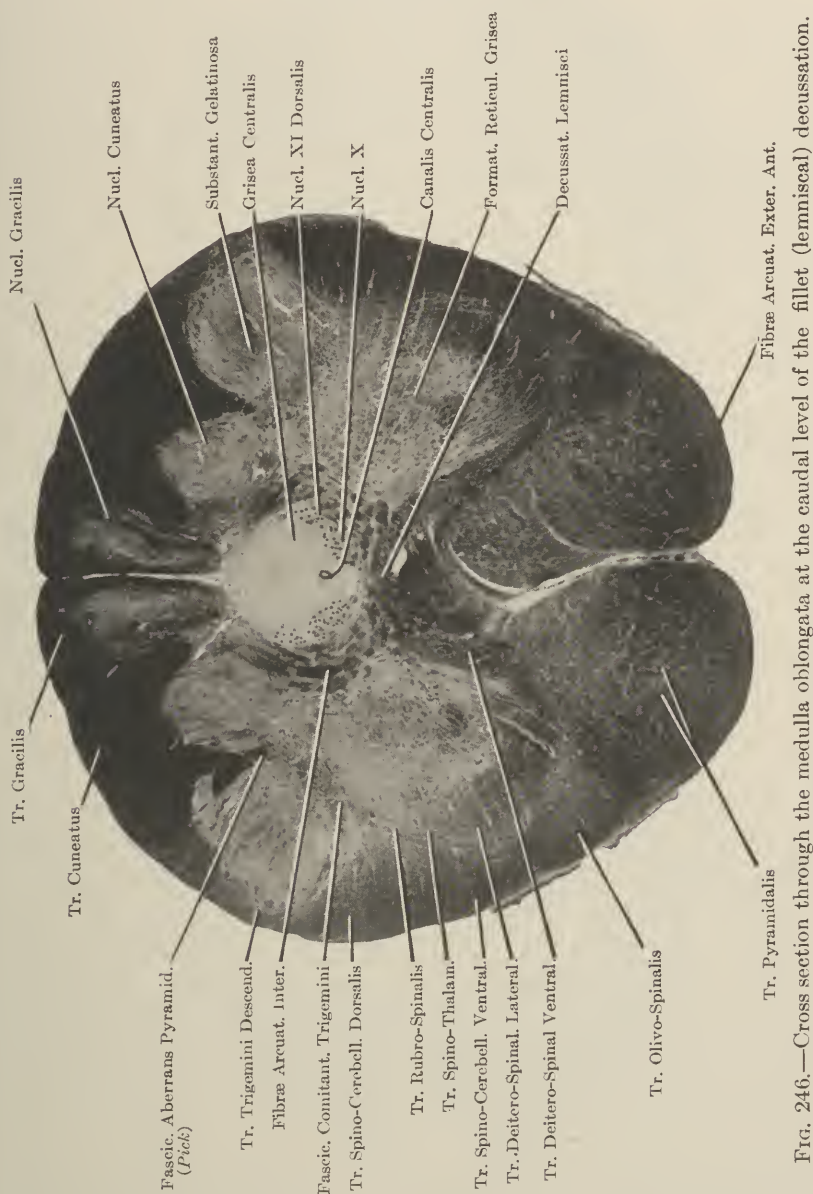


FIG. 246.—Cross section through the medulla oblongata at the caudal level of the fillet (lemniscal) decussation. (Serial section No. 245.)

formation takes on a special significance, as it is probable that the gray portion of it constitutes one of the chief elements in the control of respiration and represents in part, at least, an extensive nucleus reaching from this

point to the lower triangle of the floor of the fourth ventricle, which constitutes the chief regulating respiratory nucleus.

4. The *dorsal gray column* has increased in size by additions to the *substantia gelatinosa*. It lies directly in the transverse axis of the section. It does not occupy a position quite so close to the periphery but has interposed between it and the margin of the medulla two groups of fibers, the *external arcuate fibers* and the *descending root of the trigeminal nerve*. The neck and body of the dorsal gray column have disappeared and the gray substance is now separated from the central gray matter by the appearance of an important group of crossing fibers which constitute the *decussation of the mesial fillet*.

5. The *central gray matter* is oval in form and much larger in size. In its dorsal migration, it is entering upon its last stages. A small tongue-like prolongation of the dorsal portion of the central gray matter makes its way into the dorso-median septum, as if by this wedge the dorsal columns are finally made to diverge, and the central gray matter itself comes into the floor of the fourth ventricle. This tongue of gray matter varies in size and conspicuity in different specimens. The central canal has become enlarged and is present as an elongated slit extending from the ventral portion of the central gray matter toward its dorsal aspect.

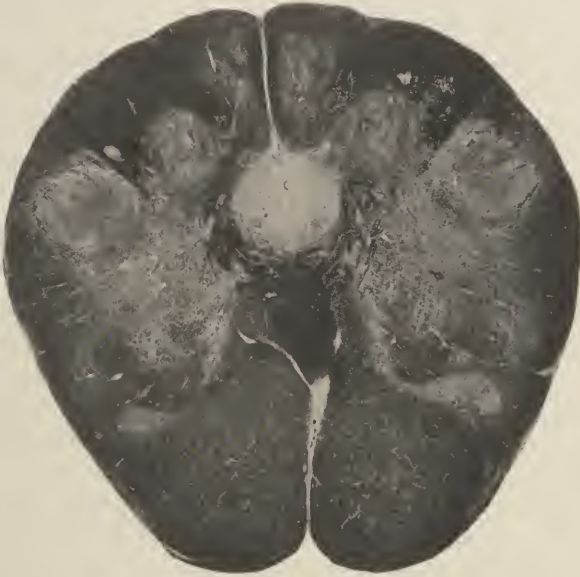
Along the margin of the central gray matter are scattered groups of cells, the most ventral of which represents the caudal portion of the *nucleus hypoglossi*. This nucleus gives rise to the twelfth cranial nerve. Dorsal and lateral to this group of cells is the continuation of the *nucleus dorsalis accessorii*, and between these two nuclei is the caudal extremity of the *dorsal nucleus of the vagus* (*nucleus dorsalis vagi*). Along the dorsal margin of the central gray matter, situated upon either side of the tongue-like process which projects into the dorso-median septum, are the fibers constituting the *fasciculus longitudinalis dorsalis* of Schütz.

New Elements of the Gray Matter. Several new elements in the gray matter have made their appearance. Among these are two specialized collections of nerve cells situated lateral to the collected bundles of the pyramids, the *paroliva ventralis* and *dorsalis* respectively. Another new portion of gray matter at this level is situated on the ventro-lateral aspect of either pyramid. This is the *nucleus arciformis*. Mention has previously been made of the appearance of the *dorsal nucleus of the vagus nerve* in the central gray matter. The *nucleus gracilis* has increased in size and fills the entire region of the *fasciculus gracilis*. The *nucleus cuneatus* has likewise increased in size and has connected with it many smaller, scattered masses of gray matter.

Changes in the White Matter. 1. The *dorsal white column* is smaller, because of the increase in the dimensions of the *nucleus gracilis* and *nucleus cuneatus*.

2. The *lateral white column* is also smaller in its dimensions, but its three general zones may be distinguished. The circumferential zone contains the descending root of the trigeminal nerve, now a massive bundle,

ventral to which lies the dorsal spino-cerebellar tract, at this level collected into a triangular fasciculus. Immediately ventral to the tract of Flechsig



Serial Section No. 262



Serial Section No. 276

FIG. 247.—Two intervening sections between the caudal level of the fillet decussation and the caudal limit of the inferior olive showing paroliva and nucleus arciformis.

is the ventral spino-cerebellar tract and the olivo-spinal tract of Helweg. The intermediate zone contains no pyramidal fibers; it is made up of the

rubro-spinal tract, the spino-thalamic tract and the lateral Deitero-spinal tract. It also contains the formatio reticularis alba. The juxtagriseal zone consists of the formatio reticularis grisea, which is in contact mesially with the crossing fibers of the fillet decussation.

3. The *ventral white column* is made up of the collected mass of pyramidal fibers constituting the *pyramids*, whose surface expression is seen in the pyramidal eminence. In addition to this large mass of fibers are the tecto-spinal and ventral Deitero-spinal tracts. Deeply situated between the ventral aspect of the central gray and dorsal limit of the ventro-median sulcus, are the crossing fibers of the *fillet decussation*. Some of these fibers have already undergone decussation and are taking up their position as elements in the *median fillet* or *lemniscus*.

New Elements in the White Matter. The new elements in the white matter are the fibers which determine the *fillet decussation*. These are known as the *internal arcuate fibers*. They have their origin in the nucleus cuneatus and the nucleus gracilis, and as axones of cells in these nuclei sweep forward on a horizontal plane encircling the central gray matter. They reach the midline immediately ventral to the central gray matter. Here they cross from one side to the other, thus occasioning a complete decussation which is known as the *decussatio lemnisci* or *decussation of the fillet*. This decussation affords the means whereby impulses arising in one half of the body cross to the opposite half of the brain-stem and eventually enter into the contralateral cerebral hemisphere. Thus the sensory elements of conduction keep pace with the motor tract. The main sensory decussation occurs in close proximity to the major motor decussation. By means of this decussation in the sensory pathway, it is evident that impulses arising in the left leg, left arm or left side of the trunk are eventually conducted to the right hemisphere of the brain, where they become active as elements in consciousness.

Another set of fibers which sweep around the margin of the medulla arises in the nucleus cuneatus and nucleus gracilis. It then passes, in succession, the descending root of the trigeminal nerve, the dorsal spino-cerebellar and ventral spino-cerebellar tracts, as well as the tract of Helweg; it finally reaches the ventral surface of the pyramids: These are the *fibræ arcuatae externæ ventrales*, which, after passing the pyramids, dip into the ventro-median sulcus and then proceed, in part at least, to the restiform body of the opposite side. This constitutes a means of communication between the nucleus cuneatus and nucleus gracilis, and the cerebellum. It probably indicates a connection which serves the purpose of bringing to the cerebellum the afferent impulses from the muscles necessary to synergic control. The significance of these external arcuate fibers in their relation to the cerebellum on the one hand, and to the muscles on the other, is, however, a matter of debate at the present time.

The *emergent root fibers* are those of the spinal accessory nerve which follow their characteristic course backward, outward and forward, to emerge from the sulcus intermedius. In consequence of the tendency

of the substantia gelatinosa to move further ventrally, the sulcus intermedius is also following the same course and is gradually assuming a more ventral position.

Fissures. The ventro-median fissure has resumed its regularity and prominence. It is relatively deep and presents no forking in its dorsal extremity. Its depth is somewhat decreased by the crossing fibers of the fillet decussation, so that there is a considerable distance interposed between the dorsal extremity of the ventro-median fissure and the ventral aspect of the central gray matter. The dorso-median fissure has become wider and is especially prominent on the surface where it is flanked on either side by the clavæ. The depth of the fissure is considerably less than in the lower sections.

CHANGES IN THE GRAY AND WHITE MATTER AT THE CAUDAL LIMIT OF THE INFERIOR OLIVE. *Changes in the Gray Matter.* 1. The *ventral and lateral gray columns* at this level have disappeared.

2. The *reticular formation* is much larger and divisible into a lateral portion, the *formatio reticularis grisea*, and a mesial portion, the *formatio reticularis alba*.

3. The *dorsal gray column* has lost its definition. The enlarged caput of the column is present as a much increased substantia gelatinosa which lies mesial to the large bundle of the descending spinal root of the trigeminal nerve. The neck and body of the dorsal gray column have disappeared, and a complete separation of this portion of the gray substance of the central gray matter is determined by the arcuate fibers sweeping forward and then inward from the nuclei of the dorsal white column.

4. The *central gray matter* shows the consummation of its dorsal migration, and the tongue-like process noted before now projects between the opposed edges of the dorsal columns. These columns are diverging to permit the gray matter to form the floor of the fourth ventricle. The thin process of gray matter projecting between the lips of the dorsal columns is the *obex*. The central gray matter on its lateral and ventral aspects is invested by the internal arcuate fibers. In its most ventral portion, it shows a cluster of large motor cells, the *nucleus hypoglossi*. Immediately dorso-lateral to this nucleus is the *nucleus dorsalis vagi*. Dorsal to this is the *nucleus dorsalis accessorii* and in a still more dorsal position is the *nucleus radialis spinalis glossopharyngei*. Interposed between the *nucleus hypoglossi* and the *nucleus dorsalis vagi* are the fibers which make up the fasciculus longitudinalis dorsalis of Schütz. The central canal is an elongated space tending to occupy a more dorsal position in the central gray matter.

New Elements in the Gray Matter. The most important addition to the medulla oblongata at this level is the *inferior olive* (*nucleus olivaris inferior*) which presents itself as a thin band of convoluted gray matter containing cells of various sizes, many of which are large stichochrome cells. This collection of gray matter is situated dorso-lateral to the pyramids and ventral to the substantia gelatinosa. In connection with it are the paroliva

dorsalis and the paroliva ventralis. The accessory portions of the inferior olive are actually integral parts of the olive which appear as detached from



Fig. 248.—Cross section through the medulla oblongata at the caudal level of the inferior olive. (Serial section No. 318.)

the general mass of gray matter. Dorsal to the olive and ventral to the substantia gelatinosa, in a position about halfway between the two formationes reticulares albæ, there appears a nucleus containing large motor cells.

From this nucleus fibers make their way dorso-mesially where they come into relation with the dorsal nucleus of the vagus. They then turn forward and outward to reach the postolivary sulcus. This is the *nucleus ambiguus*, which gives rise to important fibers of the vagus nerve.

In the intermediate zone of the lateral white column, immediately mesial to the ventral spino-cerebellar tract, appears the *nucleus reticularis lateralis*, while dorso-lateral to the substantia gelatinosa is a collection of small-sized cells forming the *nucleus marginalis dorsalis* of Ziehen. The nucleus gracilis and nucleus cuneatus occupy the entire dorsal column. The dorsal nucleus of the vagus has increased in size. It contains large cells of the motor type and many smaller cells which serve in a capacity of



FIG. 249.—Cross section through the medulla oblongata, showing the approach of the central gray substance to the dorsal aspect of the stem as the fourth ventricle is about to appear. (Serial section No. 346.)

sensory relays. The *nucleus arciformis* has enlarged and become more mesial in its position.

Changes in the White Matter. 1. The *dorsal white column* has disappeared, with the exception of a few ascending strands of the column of Burdach, in relation with the *nucleus cuneatus* and the *nucleus cuneatus externus*.

2. The *lateral white column* is reduced in size, due not only to the removal of the pyramidal tract, but because of the appearance of the inferior olive.

In the circumferential zone, the most dorsal element is the descending spinal tract of the trigeminal nerve. Its external surface is crossed by a few of the external arcuate fibers. The main portion of the dorsal spino-cerebellar tract is turned in an oblique direction about to pass into a dorsal position, from which it ultimately enters the restiform body. The ventral spino-thalamic tract passes dorsal to the olive, while the tract of Helweg is no longer discernible in the cross section. Along the outer margin of the inferior olive is a thick bundle of fibers running an oblique or horizontal course. This fasciculus constitutes the *vellus olivæ inferioris*.

The intermediate zone presents an area dorsal to the olive known as the *retro-olivary portion of the reticular formation*. In this are the spino-thalamic, the rubro-spinal and the lateral Deitero-spinal tracts, as well as the formatio reticularis alba. The region formerly occupied by the juxtagriseal portion of the lateral white column now contains the formatio reticularis grisea. Many arcuate fibers cross through the intermediate and juxtagriseal zones of the lateral white column. These fibers finally enter the mesial fillet of the opposite side. Their presence gives the cross section the appearance of alternating stripes of gray and white matter.

3. The *ventral white column* consists of the collected mass of the pyramidal fibers constituting the pyramids, and the collection of fibers extending from the dorsal aspect of the pyramids to the ventral surface of the central gray matter, the mesial fillet. The *mesial fillet* has as its lateral boundary upon either side the medial ventral accessory olive (paroliva medio-ventralis). The line along which the two fillets are in juxtaposition is marked by an area of thickened white matter constituting the *raphé*.

New Elements in the White Matter. Several new elements have made their appearance, of which the most important is the *central tegmental tract*. This forms part of the *vellus olivæ inferioris*. It is found upon the peripheral surface of the inferior olive. The decussation of the fillet has already been observed in the next lower section, where the crossing was accomplished by a compact bundle of decussating fibers. At this level, the decussation consists of more loosely arranged bundles of fibers forming the *fibrae arcuatae internæ*. These fibers arise in the nucleus cuneatus and nucleus gracilis, sweep forward in large arcs and cross the median line to enter the median fillet. The fasciculi comitantes trigemini are still present in a position mesial to the substantia gelatinosa, and a small bundle ventral to these accompanying fasciculi indicates the fasciculus pyramidalis aberrans of Pick. The *fibrae arcuatae externæ ventrales* extend along the latero-ventral surface, while the *fibrae arcuatae externæ dorsales* encircle the dorsal surface of the medulla.

Emergent Root Fibers. Emergent root fibers of the hypoglossal nerve arise in the nucleus of that nerve and make their way forward. Some of these fibers are in close relation with the olive and emerge from the preolivary sulcus. Emergent root fibers arising in the nucleus ambiguus of the vagus nerve follow a course similar to those of the spinal accessory nerve, first extending inward and backward, then coming into proximity with the dorsal vagal nucleus, and finally turning by a sharp bend outward to emerge

in the postolivary sulcus. This circuitous route of the emergent fibers of the eleventh and tenth nerves is a characteristic common to the nerves of this group.



Fig. 250.—Cross section through the caudal angle of the fourth ventricle. (Serial section No. 391.)

Fissures. The ventro-median fissure is much more shallow than is the case in the next lower level, due to the interposition of the fillet between

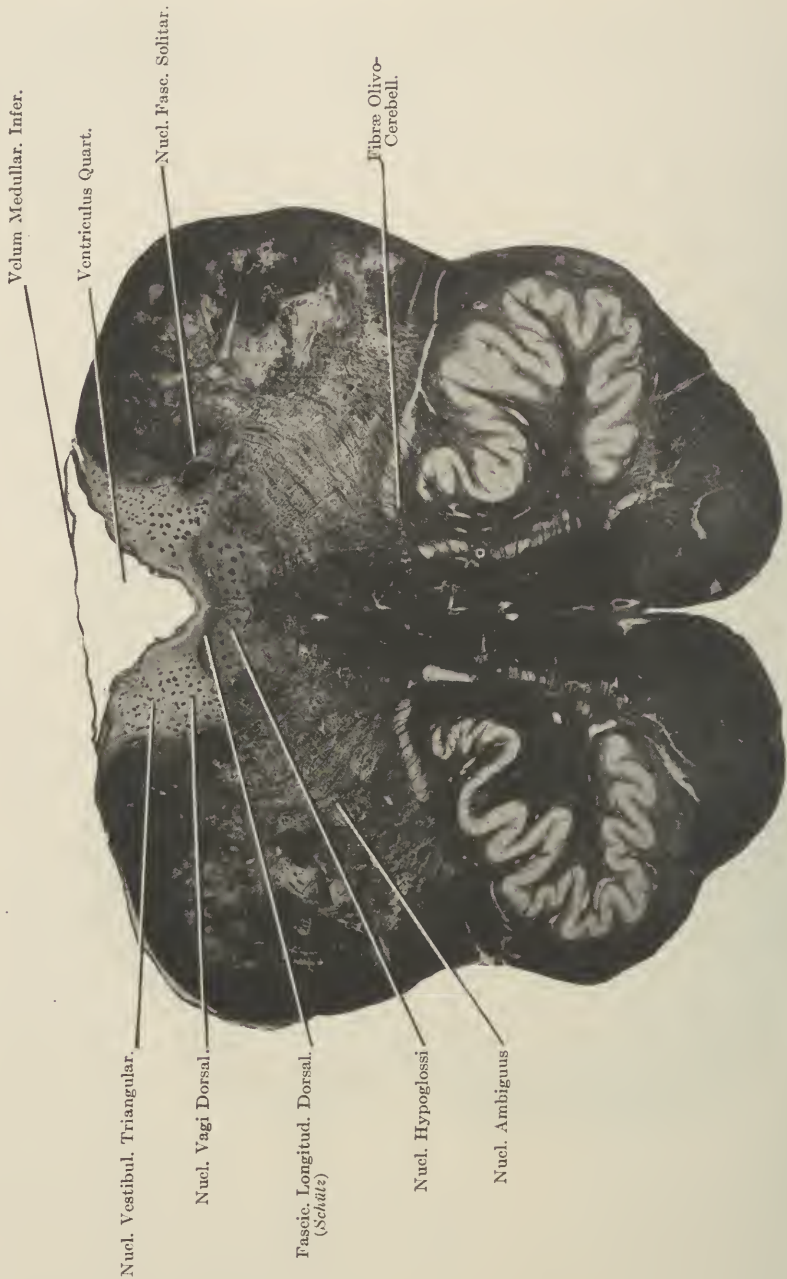


FIG. 251.—Cross section through the medulla oblongata showing the caudal portion of the fourth ventricle.
(Serial section No. 405.)

the central gray matter and the ventral surface of the medulla. The dorso-median fissure has become a wide cleft and is about to be replaced by the opening which forms the fourth ventricle.

CHAPTER XVII

THE MEDULLA OBLONGATA

INTERNAL STRUCTURE AND HISTOLOGY OF THE MEDULLA

CHANGES IN THE GRAY AND WHITE MATTER AT THE LEVEL THROUGH THE MIDDLE OF THE INFERIOR OLIVE. *Changes in the Gray Matter.* 1. The *ventral gray column* as well as the *lateral gray column* is not represented in this level.

2. The *formatio reticularis* presents its two divisions, the *formatio reticularis grisea* and the *formatio reticularis alba*.

3. The *dorsal gray column* still presents the *substantia gelatinosa* which bears its constant relation to the descending root of the trigeminal nerve.

4. The *central gray matter* has achieved its complete dorsal migration and has extended itself to form the floor of the fourth ventricle. The central canal has opened widely. Its ventral surface forms the floor of the ventricle, while its roof-plate, now much attenuated, and adherent to the pia mater, forms the chorioid plexus of the fourth ventricle. The ventricle appears as a triangular space bounded ventrally by the central gray matter and dorsally by the chorioid plexus. The surface of the central gray matter is thrown into several elevations which project into the ventricle; one of these is a mesial protuberance separated from a lateral protuberance by means of a sulcus. This sulcus is the remnant of the *sulcus limitans* and delimits the basal from the alar plate. All of the floor of the ventricle lying mesial to the sulcus limitans is devoted to motor activities, while that portion of the floor lateral to the sulcus is designed for sensory activities.

The special structures in the central gray matter are the *nucleus hypoglossi*, dorsal to which is the *nucleus intercalatus of Staderini*. Dorso-mesial to the hypoglossal nucleus is a collection of fine fibers forming the fasciculus longitudinalis dorsalis of Schütz. Beneath the sulcus limitans is the *nucleus dorsalis vagi*, made up of large motor cells and many smaller nerve cells. Lateral to the dorsal vagal nucleus is a group of small cells in connection with a well-defined fasciculus of nerve fibers. These nerve cells constitute the *nucleus fasciculi solitarii*, while the bundle of nerve fibers is the *fasciculus solitarius* itself. Lateral to the nucleus solitarius is a triangular field of gray matter containing cells of medium size; this is the *nucleus vestibularis triangularis*, one of the receiving centers for the vestibular division of the eighth nerve. Occupying a dorso-lateral position, a special prolongation of the central gray matter produces a prominence known as the *tuberculum acusticum*. This is the *dorsal acoustic nucleus* in

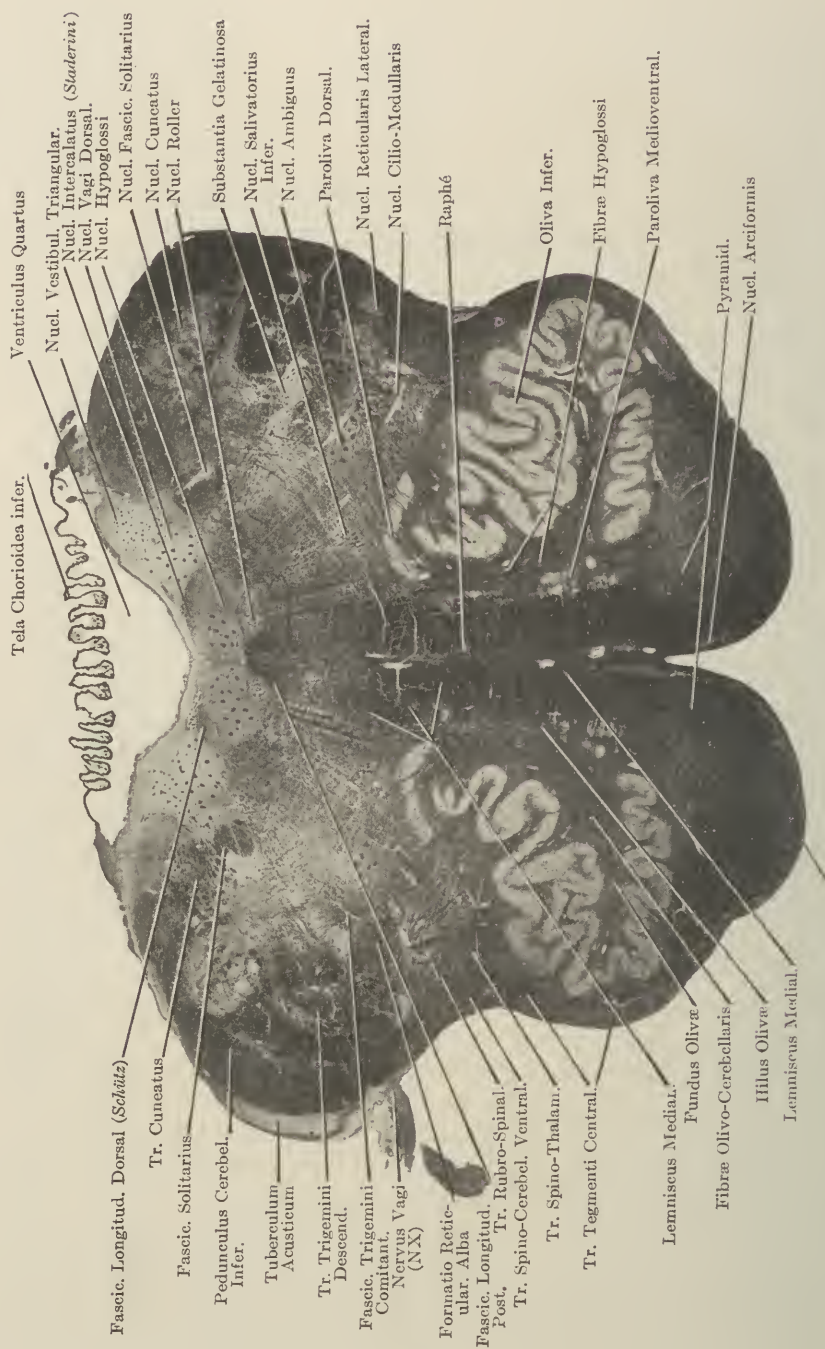


Fig. 252.—Cross section of the medulla oblongata through the middle of the inferior olive. (Serial section No. 436.)



Serial Section No. 450



Serial Section No. 458

FIG. 253.—Cross sections of the medulla oblongata intervening between the middle of the inferior olive and its summit. These sections show the intramedullary course of the vagus and hypoglossal nerves.

connection with the cochlear portion of the eighth nerve. It is evident that all elements mesial to the sulcus limitans in the floor of the fourth ventricle are motor in character, while those lateral to this sulcus are sensory in function. The actual floor of the fourth ventricle is covered by ependymal cells, beneath which is a thin stratum of gray matter containing nerve cells of the smallest size. This is the *subependymal layer*.

New Elements in the Gray Matter. In addition to the nuclei mentioned in connection with the floor of the fourth ventricle, a large group of cells appears ventro-mesial to the hypoglossal nucleus. This is the *nucleus prepositus of Roller*. A small nucleus has made its appearance at this level dorsal to the nucleus ambiguus and ventro-mesial to the substantia gelatinosa. This is the *nucleus salivatorius inferior*. Another collection of medium sized motor elements, identified by Déjerine in connection with the control of the intrinsic muscles of the eye, is the *nucleus cilio-medullaris* situated in the reticular formation ventral to the dorsal nucleus of the vagus. This nucleus controls the dilator fibers of the iris, the ciliary muscle and Horner's muscles of the upper lid and orbit. Injury or disease of this region produces among other symptoms, enophthalmos, myosis, inequality of the pupils and slight drooping of the upper eyelid.

The nucleus fasciculus solitarius is connected with the gustatory sense, while the tuberculum acusticum constituting the dorsal acoustic nucleus, is related to the cochlear division of the eighth nerve, and thus with the sense of hearing.

The nucleus gracilis at this level has disappeared and the nucleus cuneatus is much reduced in size. It occupies a position lateral to the *nucleus vestibularis triangularis* and mesial to the fibers which constitute the inferior cerebellar peduncle (*corpus restiforme*). The inferior olive appears as a convoluted band of gray matter having a fundus and a hilus. The fundus contains a mass of white fibers which enter and leave at the hilus. The nucleus arciformis has increased in size and occupies its usual position mesial to the pyramids. The nucleus ambiguus has enlarged, and the nucleus reticularis lateralis is present though much reduced in size.

Changes in the White Matter. 1. The *dorsal white column* at this level has disappeared, due to the opening of the fourth ventricle and the general ventral shift of all the elements which formerly occupied this position in the spinal cord.

2. The *lateral white column* shows considerable rearrangement, due especially to the dorsal shift which has taken place in the dorsal spino-cerebellar tract. This tract, together with fibers coming from the inferior olives, the nucleus cuneatus and the nucleus gracilis, has formed a massive bundle known as the *corpus restiforme* or *inferior cerebellar peduncle*, which lies ventral to the tuberculum acusticum and lateral to the remains of the nucleus cuneatus. The ventral spino-cerebellar tract holds its usual position in the circumferential zone, interposing itself between the inferior olive and the restiform body. Along the ventro-lateral aspect of the inferior olive is a well-marked descending tract constituting the *central tegmental*

tract of Bechterew. It is incorporated with many fibers which form the *vellus olivæ inferioris*.

The intermediate zone of the lateral white column is reduced in size and contains the descending spinal root of the trigeminal nerve, the spino-thalamic and rubro-spinal tracts, and the *formatio reticularis alba*.

The *juxtagriseal* portion of the lateral white column consists of the *formatio reticularis grisea*.

3. The *ventral white column* extends from the ventral surface of the medulla as far back as the ventral surface of the central gray matter. The ventralmost element is the *pyramid*, dorsal to which is the *mesial fillet*. The dorsalmost element in the ventral white column is the *fasciculus longitudinalis posterior*. The hilus of either olive is directed dorso-mesially, and from it emerge many fibers which arise in the olive. These fibers pass directly toward the median line, which they cross, and after sweeping dorso-laterally, they ultimately enter the restiform body on the opposite side. This constitutes the *inferior olivary decussation*. It establishes a contralateral connection between the inferior olive and the cerebellum. Many fibers arising in the *substantia gelatinosa* make their way into the ventral white column, crossing the mid-line and entering into the formation of an ascending tract connected with the trigeminal nerve. This tract, in all probability, is part of the secondary pathway for the fifth nerve, and represents the avenue of conduction over which impulses from the surfaces of the head and face pass on their way to the cerebral cortex. Scattered among the dorsal fibers of the *fasciculus longitudinalis posterior* are some large motor cells which make up the *nucleus of Roller*.

New Elements in the White Matter. The appearance at this level of the *fasciculus longitudinalis posterior* as a discrete bundle is the most prominent addition to the white substance. This fasciculus represents an intersegmental association tract whose purpose is the coordination of the several groups of eye muscles, and the correlation of such movements with the reactions of the vestibular mechanism. The *fasciculus solitarius* is especially prominent and occupies a position ventro-lateral to the dorsal vagal nucleus. The *inferior olivary decussation* is also a feature at this level as well as the decussation of fibers arising in the *substantia gelatinosa* and taking part in the formation of the secondary trigeminal pathway.

Emergent and Entrant Root Fibers. The emergent root fibers of the hypoglossal and the vagus nerves are seen at this level. The vagal fibers are joined by afferent elements coming from the vagal ganglia. These afferent fibers make their way to the dorsal vagal nucleus, which acts as a sensory relay station in the pathway of this nerve.

Fissures. The ventro-median fissure, although conspicuous on the surface, due to the prominence of the pyramids which rise upon either side of it, has become less deep because of the *inferior olivary decussation* and the position of the *mesial fillet*.

The dorso-median fissure no longer exists. The columns bounding it have become divergent in such a manner as to bring the central gray matter into the floor of the fourth ventricle.

CHANGES IN THE ARRANGEMENT OF THE GRAY AND WHITE MATTER AT THE CEPHALIC LIMIT OF THE INFERIOR OLIVE. *Changes in the Gray Matter.* All semblance of (1) the ventral gray column and (2) the lateral gray column is lost, and no structure in any way similar to these elements may be discerned. The remnant of (3) the dorsal gray column is represented in a much reduced substantia gelatinosa which occupies a position mesial to the restiform body and lateral to the formatio reticularis alba.

4. The *central gray matter* forms the floor of the fourth ventricle which at this point has its greatest transverse extent, reaching from one lateral recess to the other. The groups of cells entering into the central gray matter are as follows:

(a) The *nucleus prepositus hypoglossi*, a collection of medium-sized stichochrome cells situated below (b) the *nucleus fasciculus teretis*, a collection of small nerve cells. Lateral to the nucleus prepositus is (c) the *nucleus vestibularis triangularis* connected with the vestibular mechanism. Ventral to this nucleus is (d) the *nucleus glossopharyngei*, made up of large motor elements interspersed among a much greater number of small cells of the sensory type. Lateral to the triangular vestibular nucleus is (e) the *nucleus dorsalis acustici*, in a position subjacent to the floor of the fourth ventricle and dorsal to the inferior cerebellar peduncle. Ventral to the dorsal acoustic nucleus and mesial to the inferior cerebellar peduncle is a large nucleus containing large cells of the motor type. This is (f) the *nucleus of Deiters* or the *nucleus magno-cellularis vestibularis*.

Interposed between the nucleus glossopharyngei and Deiters' nucleus is a massive bundle of coarse fibers which follow a descending course and constitute the *descending vestibular root*. The floor of the ventricle is covered by ependymal cells, beneath which in many cases the secondary fibers arising in the dorsal and ventral acoustic nuclei cross toward the midline where they undergo decussation. These fibers are the *striæ acusticæ*. The nucleus ambiguus has disappeared, but occupying its usual position, midway between the inferior olive and the substantia gelatinosa, is the caudal extremity of the large motor nucleus of the facial nerve, the *nucleus facialis*. The nucleus arciformis has increased in size, in some places making its way in among the pyramidal fibers and extending well into the depth of the ventro-median fissure. Another nucleus seen at this level extends along the mesial aspect of the fasciculus longitudinalis posterior and the mesial fillet. This is the *nucleus ventralis inferior*. The most important new element at this level is *Deiters' nucleus*, which has already been defined as the nucleus magno-cellularis vestibularis. The reticular formation shows a marked increase in the size of the formatio reticularis alba with a corresponding reduction in the size of the formatio reticularis grisea.

Changes in the White Matter. Both *dorsal columns* have disappeared and the *lateral columns* have been subjected to much alteration. In the circumferential zone, the restiform body or inferior cerebellar peduncle forms the most dorsal element. Ventral to it is the ventral spino-cerebellar



Fig. 254.—Cross section through the medulla oblongata at the level near the summit of the inferior olive. (Serial section No. 482.)

tract, in front of which is situated the central tegmental tract and the vellus olivæ inferioris. The intermediate zone is made up of the spinal root of the trigeminal nerve, the rubro-spinal and the spino-thalamic tracts. Each of these occupies its usual position. A number of horizontally crossing fibers pass through the intermediate zone; they arise in the olives and are making their way from this source to the inferior cerebellar peduncle. The juxtargiseal portion of the lateral white column consists of the formatio reticularis grisea.

The *ventral white column* contains the pyramid, dorsal to which in the order mentioned are the collected bundle of the fillet, the fasciculus predorsalis and the fasciculus longitudinalis posterior. A number of external arcuate fibers dip into the ventro-median sulcus and give the raphé increased prominence. These fibers undergo decussation in the midline, from which point they may be traced in either direction to the inferior cerebellar peduncle. Some fibers from Deiters' nucleus and from the vestibular triangular nucleus pass from these sources to the raphé where they cross and enter into the formation of the opposite fasciculus longitudinalis posterior.

Emergent and Entrant Root Fibers. A few of the most cephalic fibers of the hypoglossal nerve are seen emerging from the preolivary sulcus at this level. Fibers arising in the nucleus glossopharyngei proceed outward to the postolivary sulcus, where they escape and are joined by afferent sensory elements making their way to the nucleus fasciculus solitarius or the dorsal sensory nucleus of the glossopharyngeal nerve. The entering fibers of the cochlear division of the eighth nerve come into relation with the ventral accessory acoustic nucleus; passing dorsally and mesially they enter into connection with the dorsal acoustic nucleus.

Fissures. The ventro-median fissure is again prominent because of the large size of the pyramids and the increased dimensions of the arciform nuclei. The two lateral recesses project laterally from the floor of the fourth ventricle and come into relation with the ninth and tenth nerves laterally, and with the seventh and eighth nerves situated cephalad to them.

Summary of the Changes which Occur in the Arrangement of the Gray and White Matter of the Medulla Oblongata. The changes which take place in the gray matter occasion the most marked alterations in the ventral and lateral gray columns, both of which ultimately disappear and are replaced by structures which are not present in the spinal cord.

The lateral migration of the dorsal gray column and its marked increase in size, together with its relation to the descending spinal tract of the trigeminal nerve, and the loss of its neck and body, constitute other conspicuous alterations in the gray matter.

The migration which has occasioned greatest differences in the appearance between sections of the medulla and the spinal cord is that which affects the central gray matter, gradually forcing this portion of the gray substance into a more dorsal position, until finally it participates in the formation of the floor of the fourth ventricle.

In addition to this migration dorsally there is a pronounced increase

in the size of the central gray matter, which gives it new significance in the administration of splanchnic functions. In consequence of this increase in the central gray matter, provision is made for the several nuclei of the vagus, of the glossopharyngeus and of the hypoglossal nerves, as well as the vestibular and cochlear divisions of the eighth nerve.

The expansion of the *formatio reticularis* is of much moment in the formation of the internal structure of the medulla, especially the *formatio reticularis grisea*. This portion of gray matter is believed to form one of the most important nuclei controlling respiratory activity.

THE APPEARANCE OF NEW ELEMENTS IN THE GRAY MATTER. A number of collections of nerve cells not observed in the spinal cord are found at different levels of the medulla oblongata. Certain of these new cell groups require particular attention:

1. The *nuclei of the dorsal column*, the *nucleus cuneatus* and *nucleus gracilis*. These new elements in the gray matter cause the pronounced changes in the dorsal white column which, as previously explained, introduce the means of relaying sensory impulses on their way to the cerebral cortex.

2. The *dorsal nucleus of the vagus*, the *nucleus dorsalis vagi*, consists of a motor and a sensory portion. It serves the vital processes which regulate cardiac action, respiration and gastro-intestinal activity.

3. The *nucleus ambiguus* contributes fibers to the formation of the vagus, probably in the interest of controlling the larynx.

4. The *dorsal nucleus of the glossopharyngeal nerve* consists of motor and sensory elements. The *nucleus fasciculus solitarius*, is involved in the formation of the secondary pathways for the transmission of gustatory impressions from the tongue.

5. The *hypoglossal nucleus* gives rise to the nerve supplying the intrinsic muscles of the tongue. It is the only somatic motor nerve arising in the medulla oblongata. All other motor elements derived from the medulla belong to the splanchnic motor group.

6. The *nucleus of Roller* is situated upon either side of the *raphé ventral* to the nucleus of the hypoglossal nerve. To it has been attributed participation in the control of respiratory functions.

7. The *inferior olive*, with its several accessory olivary nuclei, whose function is still in doubt, seems to be related to the coordinative control of the head and eye movements.

8. The *nucleus arciformis* serves as a relay in the course of the external arcuate fibers, probably affording an accessory afferent connection between the muscles and the cerebellum by way of the inferior cerebellar peduncle.

9. *Deiters' nucleus* acts as a center for equilibratory control of the muscles in their relation to the semicircular canals, utricle and saccule.

10. The *triangular vestibular nucleus* serves in a capacity similar to that of Deiters' nucleus.

11. The *ventral and dorsal acoustic nuclei* act as relay stations in the formation of the secondary tracts forming the pathway for hearing.

12. The *facial nucleus* controls the muscles of facial expression. The caudal extremity of this nucleus in most specimens appears in the cephalic portion of the medulla.

REARRANGEMENT OF THE WHITE MATTER IN THE MEDULLA OBLONGATA. The white matter of the medulla oblongata is notable because of the decussations which take place within it. Six of these decussations occur and are of major importance:

1. The *pyramidal decussation*, which takes place at the caudal extremity of the medulla and serves to effect a contralateral connection between the cerebral motor cortex of one side and the somatic musculature of the opposite side of the body.

2. The *decussation of the fillet* is accomplished by the crossing of internal arcuate fibers. It makes possible the contralateral connection between the receptors of one side of the body and the opposite side of the cerebral sensory cortex.

3. The *inferior olivary decussation*, which brings the inferior olive of one side into relation with the cerebellar structures of the opposite side through the inferior cerebellar peduncle.

4. The *decussation of the external arcuate fibers*, which brings the nucleus cuneatus and the nucleus gracilis into relation with the opposite side of the cerebellum through the inferior cerebellar peduncle.

5. The *decussation of trigeminal fibers*, which determines a cross connection between areas innervated by the trigeminal nerve and the opposite side of the cerebral sensory cortex.

6. The *decussation of fibers from Deiters' nucleus to the fasciculus longitudinalis posterior*. This determines a partial contralateral connection in the Deiters-spinal tracts as well as between the nucleus of Deiters and the nuclei guiding the eye muscles.

REARRANGEMENT OF THE LATERAL WHITE COLUMN. In the cephalic portion of the medulla oblongata the lateral white columns are so arranged that the inferior cerebellar peduncle becomes the most dorsal element of the circumferential zone.

Ventral to this peduncle is the ventral spino-cerebellar tract.

The olivo-spinal tract of Helweg has terminated in the inferior olive, and its former place is now occupied by the central tegmental tract.

The inferior cerebellar peduncle consists of the dorsal spino-cerebellar tract, to which are added fibers from the inferior olive as well as from the nucleus cuneatus and nucleus gracilis.

The *fibræ arcuatæ externæ ventrales* encircle the lateral circumference of the medulla for a considerable distance in the mid-olivary region. The main differences between the circumferential zone of the medulla oblongata at this level and that of the spinal cord consist of the dorsal shift of the dorsal spino-cerebellar tract to enter the restiform body, the disappearance of the tract of Helweg and the assumption by the descending root of the fifth nerve of a position in the intermediate zone.

The intermediate zone of the lateral white column is much smaller than

in the spinal cord. It contains the spinal root of the trigeminal nerve with its fasciculi comitantes, also the fasciculus pyramidalis aberrans of Pick and the *formatio reticularis alba*. In the cephalic portion of the medulla no fibers of the crossed pyramidal tract occupy this position. Ventral to the *substantia gelatinosa* and dorsal to the inferior olive lie the *spino-thalamic* and *rubro-spinal tracts*.

The juxtagriseal portion of the lateral white columns consists largely of the *formatio reticularis grisea*, which belongs more properly to the gray substance. It undoubtedly has the significance of an important intersegmental association system whose chief function is connected with respiration.

REARRANGEMENT OF THE VENTRAL WHITE COLUMN. This column in the medulla oblongata is much more extensive than the corresponding region in the spinal cord. It extends from the ventral periphery to the ventral margin of the central gray matter and has, as its lateral boundaries, the inferior olives and the emergent fibers of the hypoglossal nerves. In it are the fibers constituting the *pyramids*, dorsal to which are fibers which make up the *mesial fillet*, the *fasciculus predorsalis* and the *fasciculus longitudinalis posterior*. In connection with the latter fasciculus, there are some fibers which eventually come into relation with Deiters' nucleus, forming the ventral Deitero-spinal tract, and also fibers of the tecto-spinal tract.

The essential changes in the arrangement of the white matter of the medulla oblongata depend upon the increased prominence of the ventral white column, which contains not only the pathway for volitional control over the muscles, but also part of the conduction system which serves to convey sensory impressions from the body to the cerebral cortex and has its spinal representation in the dorsal white column. This shift from the dorsal white column of the spinal cord to the ventral white column of the medulla oblongata is so complete that nothing remains in the cephalic portion of the bulb of the formerly important groups of fibers constituting the columns of Goll and Burdach. Quite as important is the shift of the pathway for volitional control from the lateral white column, which it occupies in the spinal cord, into the ventral column of the medulla.

One feature concerning the lateral white column needs emphasis, namely, the consistency with which the rubro-spinal and spino-thalamic tracts adhere to their usual spinal cord positions in making their way through this portion of the brain. The same distinction also applies to the ventral spino-cerebellar tract and the lateral Deitero-spinal tract.

CHAPTER XVIII

THE MEDULLA OBLONGATA

FUNCTIONAL SIGNIFICANCE OF THE MEDULLA

The Functions of the Gray Matter. The functions of the gray matter of the medulla oblongata may be classified with reference to the components through which they act. The chief function of this portion of the brain is represented by the splanchnic autonomy which the medulla holds over the vital processes of respiration, cardiac action, deglutition and intestinal activity. This autonomy is expressed in the activities of the splanchnic motor and splanchnic sensory components.

In addition to these splanchnic activities, the gray matter of the medulla acts as a relay station for several qualities of somatic sensibility and mediates influences which control the action of certain somatic muscles.

Splanchnic Motor Functions of the Medulla. Through the dorsal motor nucleus of the vagus and glossopharyngeus nerves, the medulla innervates many glandular effectors and involuntary muscles. Among these motor and glandular effectors are:

1. The muscles of the soft palate.
2. The constrictors of the pharynx.
3. The muscles of the esophagus.
4. The muscles of the stomach.
5. The muscles of the intestine and part of the colon as far as the descending colon.
6. The musculature of the bronchial tree and trachea.
7. The musculature of the heart.

It also innervates the salivary glands through the inferior salivary nucleus as well as exerting an effector influence over the glycogenic activity of the liver and the secretions of the pancreas. Through the vagus nerve the medulla aids in activating the glands of the stomach and intestine.

The innervation of the fauces and pharynx is effected by the glossopharyngeal nerve, while the lower portions of the respiratory and gut tracts are regulated by the vagus. The medulla oblongata controls the muscular activities of the larynx, to which impulses are supplied by the nucleus ambiguus. It also in part controls the facial muscles, through the motor nucleus of the facial nerve, which is the final common pathway for the musculature of expression and the platysma myoides muscle.

Splanchnic Sensory Functions of the Medulla. Through the sensory nuclei of the vagus and glossopharyngeus nerves, the medulla affords the following areas their splanchnic sensory supply:

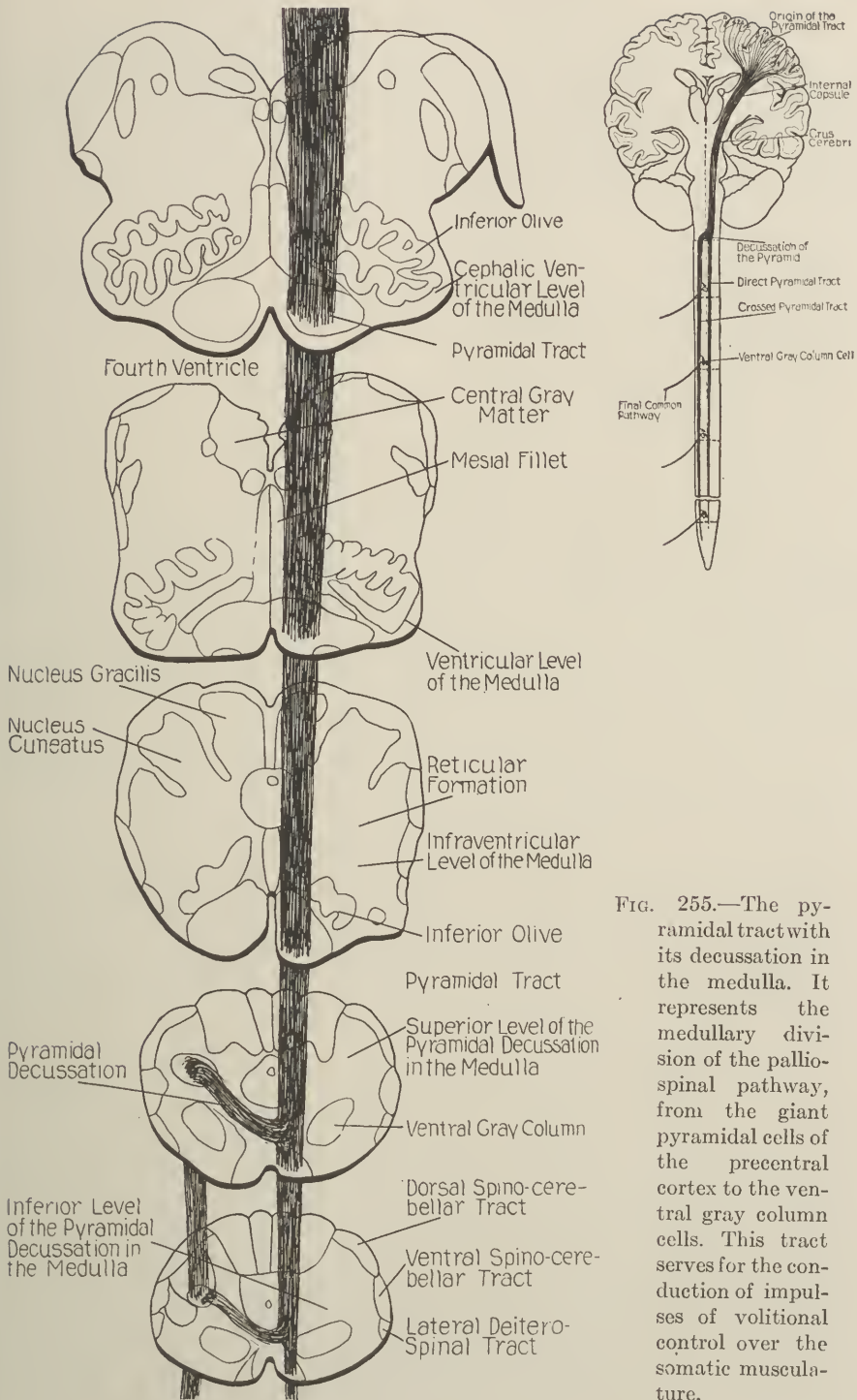


FIG. 255.—The pyramidal tract with its decussation in the medulla. It represents the medullary division of the pallio-spinal pathway, from the giant pyramidal cells of the precentral cortex to the ventral gray column cells. This tract serves for the conduction of impulses of volitional control over the somatic musculature.

1. Part of the dura mater in the region of the sinus transversus.
2. The soft palate.
3. The posterior third of the tongue with the special sense of taste. In this region it also supplies the mucosa of the Eustachian tube, and through Jacobson's branch of the glossopharyngeal nerve, the tympanic cavity, the fenestra ovalis, the fenestra rotunda, and the mucosa of the mastoid cells.
4. The pharynx and epiglottis.
5. The larynx.
6. The trachea.
7. The respiratory mucosa.
8. The mucosa of the esophagus.
9. The mucosa of the stomach.
10. The mucosa of the duodenum, jejunum and ileum.
11. The mucosa of the bile ducts.
12. The mucosa of the ascending and transverse colon.
13. The heart and pericardium.

Concerning the supply of the sense of taste to the posterior third of the tongue, the arch of the palate and the uvula, there is some difference of opinion. According to certain authorities, the trigeminus nerve supplies the sensory element, and the ninth nerve the special taste innervation. According to others, the glossopharyngeal nerve is wholly sensory, while the trigeminus is the taste nerve; some believe that each of these two nerves has a dual function, in part sensory and in part taste. The central receiving station for the sense of taste is the nucleus fasciculus solitarius. The root fibers entering into connection with this nucleus arise chiefly in the seventh and ninth nerves, although the tenth nerve may make a small contribution to it.

The medulla innervates the anterior two-thirds of the tongue with special splanchnic sensory fibers of taste through the *chorda tympani*, the sensory division of the facial nerve.

Somatic Motor Functions of the Medulla Oblongata. Through the hypoglossal nerve, the medulla supplies all of the intrinsic muscles of the tongue. These muscles are derived from myotomes and hence the tongue is to be regarded as belonging to the somatic motor system.

By means of the inferior olive, the medulla furnishes an important center for the combined synergic control of the eye and head movements.

The functional significance of the inferior olivary body is not clear at present. Bechterew regards it as a center for static equilibrium. This supposition does not seem to accord well with the facts. The olive reaches its highest development in those animals requiring the most exact cooperative coordination between eye movements and movements of the head. The anatomical connections of the olive lead to the belief that its function is the coordination of these movements. Its connection with the cerebellum through the olivo-cerebellar fibers, with the nuclei of the oculomotor apparatus through the central tegmental tract and with the upper cervical segments of the spinal cord through the tract of Helweg, seems to point to

a mechanism which is especially well adapted to bring into relation movements of the eyes and of the head.

The Somatic Sensory Functions of the Medulla Oblongata. The medulla oblongata serves as the chief relay station in the pathway of impulses arising in the inner ear and proceeding to the auditory area of the brain to serve the purposes of audition. These fibers develop in connection with the cochlear portion of the eighth nerve. The more primitive division of the eighth nerve, that which is connected with the semicircular canals, the utricle and saccule, also receives a relay in the medulla. This relay connects with certain areas of the brain involved in equilibratory control. According to some authorities, the fibers arising in the organs of the vestibular system belong to the proprioceptive system, as do also the fibers which arise in the muscles, joints and bones. There can be no objection to considering the vestibular fibers as integral parts of the proprioceptive system, provided it is recognized that their organs are genetically related to the ectoderm. The end-organs of the muscles, joints and bones, on the other hand, are related to the mesoderm. The medulla, by means of the nucleus cuneatus, the nucleus gracilis and the substantia gelatinosa, affords relays for the discriminative types of sensibility coming from the leg and lower trunk, from the arm and upper trunk, from the back of the head and face. It is probable that through the relay of the substantia gelatinosa all types of sensory impulses are transmitted to the cerebral cortex. A small aberrant branch of the vagus nerve supplies a cutaneous area in the external ear immediately surrounding the external auditory canal. This innervation is effected through Arnold's nerve.

Simple Reflexes Mediated through the Medulla Oblongata. *The Coughing Reflex.* This reflex may be determined by stimulation of the mucous membrane of the pharynx, of the larynx, of the trachea, of the bronchial tree or of the external auditory canal. The afferent impulses are conveyed by branches of the vagus nerve. They reach the dorsal nucleus of the vagus, and are transmitted to the respiratory nucleus of the medulla which occasions a forceful expiratory effort preceded by a deep inspiration.

The Swallowing Reflex. This reflex is occasioned by mechanical stimulation of the wall of the pharynx, and is activated through branches of the vagus and glossopharyngeal nerves. The motor center of the reflex is in the dorsal vago-glossopharyngeal nucleus. Section of the glossopharyngeal nerve causes the disappearance of the swallowing reflex.

Vomiting or Regurgitation Reflex. This reflex may be determined by abnormal stimuli in the region of the cardia of the stomach, in the wall of the pharynx, in the gastro-intestinal tract, or in the internal ear. The afferent arm of the reflex is furnished by the vagus and glossopharyngeal nerves. The motor center is in the dorsal motor nucleus of the vagus, a special subdivision of which is sometimes spoken of as the *vomiting center*. The efferent arm of the reflex is furnished by the vagus nerve together with the somatic nerves to the abdominal wall and diaphragm.

The Salivary Reflex. This reflex may be determined by stimulation of

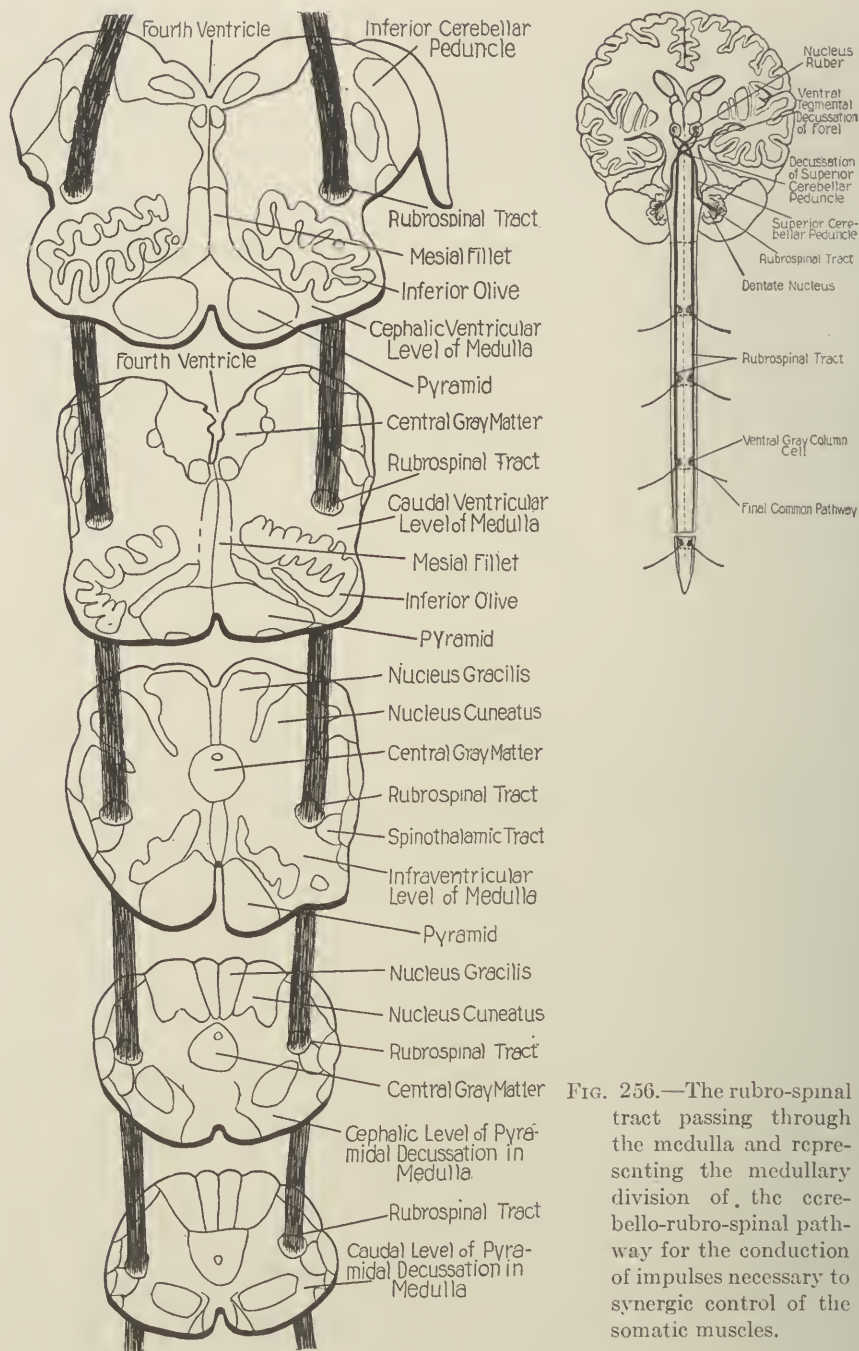


FIG. 256.—The rubro-spinal tract passing through the medulla and representing the medullary division of the cerebello-rubro-spinal pathway for the conduction of impulses necessary to synergic control of the somatic muscles.

the mucous membrane of the vestibule of the mouth, of the lips, or of the general mucosa of the oral cavity by chemical, mechanical, or other gustatory stimuli. Stimulation of the chorda tympani, of the oral distribution of the trigeminus or of the glossopharyngeal area, will cause the passage of afferent impulses to the nucleus salivatorius inferior in the medulla, and determine effector impulses activating the salivary glands.

The Sneezing Reflex. This reflex may be determined by afferent impulses received from the mucous membrane of the nasal cavity by way of the trigeminal nerve. When transmitted to the respiratory nucleus in the medulla they activate a forceful expiratory effort forcing the air through the nasal passages under considerable pressure.

The Sucking Reflex of the New-Born. This may be regarded as a simple reflex, inasmuch as it is determined by the presence of an object in the mouth of the infant, thus stimulating the trigeminal and glossopharyngeal nerves to transmit sensory impulses to the medulla, from which arise motor impulses distributed through the hypoglossal, glossopharyngeal, and facial nerves, bringing the respiratory centers into play at the same time. In later life the reflex is conditioned by control from higher divisions of the brain.

The Medulla in its Relations to Special Functions. The medulla oblongata has autonomous control over certain vital functions, chief among them being those of respiration, cardiac activity, ingestion, deglutition and digestion of food, circulation, metabolism and secretion.

THE MEDULLA OBLONGATA IN ITS RELATION TO RESPIRATION. In considering the relation of the medulla oblongata to the function of respiration, it is not proposed to discuss the physiology of this mechanism as a whole, but rather the rôle which the myelencephalon plays in it.

The Muscle Groups Active in the Respiratory Mechanism. The respiratory mechanism brings into action certain muscular groups of the body. These may be classified as (1) the principal groups, (2) the ordinary accessory groups, and (3) the extraordinary accessory groups. In extreme emergency, it is probable that few muscles of the body are exempt from participation in the respiratory effort.

1. *The Principal Muscle Groups Active in the Respiratory Mechanism.*

(a) The chief muscle acting in respiration is the diaphragm, which is supplied by the phrenic nerve, the latter arising in the third, fourth and fifth cervical segments of the spinal cord.

(b) The external intercostal muscles and the intercartilaginous muscles, which are supplied by the intercostal nerves arising in the thoracic segments of the spinal cord, from the first to the twelfth inclusive.

(c) The long and short levator of the muscles of the ribs, supplied by the dorsal branches of the intercostal nerves.

These groups of muscles act in ordinary inspiration, while in ordinary expiration there is no actual muscular contraction, since the elasticity of the tissues of the thoracic basket, together with that of the lungs and the abdominal muscles, determines the expiratory movement.

2. *The Ordinary Accessory Muscles Active in the Respiratory Mechanism.*

(a) The serratus posticus superior muscle, supplied by the dorsalis scapulæ nerve, which arises in the cervical segments of the spinal cord.

(b) The sterno-cleido-mastoid muscle, supplied by the spinal accessory nerve.

(c) The trapezius muscle, supplied by the spinal accessory nerve.

(d) The rhomboid muscles, supplied by the nerve to the rhomboids which arises in the cervical segments of the spinal cord.

(e) The pectoralis minor muscle, supplied by the internal anterior thoracic nerve.

Certain muscle groups serve to assist the respiratory act by increasing the capacity of the passages admitting the air. These are:

(a) The depressors of the larynx, the sterno-hyoid and the sterno-thyroid muscles, supplied by the descendens hypoglossi nerve.

(b) The crico-arytenoid posterior and the thyro-arytenoid separate the vocal cords. These muscles are supplied by the recurrent laryngeal nerve, a branch of the vagus.

(c) The depressors of the lower jaw, supplied by the trigeminal, facial and hypoglossal nerves.

(d) The depressors of the tongue, supplied by the hypoglossal nerve and the pharyngeal plexus.

(e) The levator palati, supplied by the pharyngeal plexus.

(f) The azygos uvulæ, supplied by the pharyngeal plexus.

(g) The dilator narium anterior and posterior, supplied by the facial nerve.

(h) The levator alæ nasi, supplied by the facial nerve.

In deep expiration the abdominal muscles take part by compressing the abdomen. These muscles are supplied by the abdominal branches of the eighth to the twelfth intercostal nerves inclusive.

The internal intercostal muscles also act in inspiration to increase the capacity of the thoracic cavity.

3. *Extraordinary Accessory Groups Active in Respiration.* In labored and extreme respiratory effort, the entire musculature of the body may act. This is seen in cases of suffocation, when the whole body is thrown into convulsive movement in the struggle to gain air.

Respiratory Coordinating Center of the Medulla Oblongata. The fact that such a wide range of the muscles may come into action to meet the requirements of respiration, indicates the necessity of some coordinating center which shall have control over the entire skeletal musculature of the body and which, under extreme circumstances, may make use of these muscles in a most effective manner. The presence of such a coordinating center for respiration has long been suspected and is still a subject of debate.

The first exact localization of this center was made by Legallois and Flourens, who placed it in the medulla oblongata in the region of the *cala-*

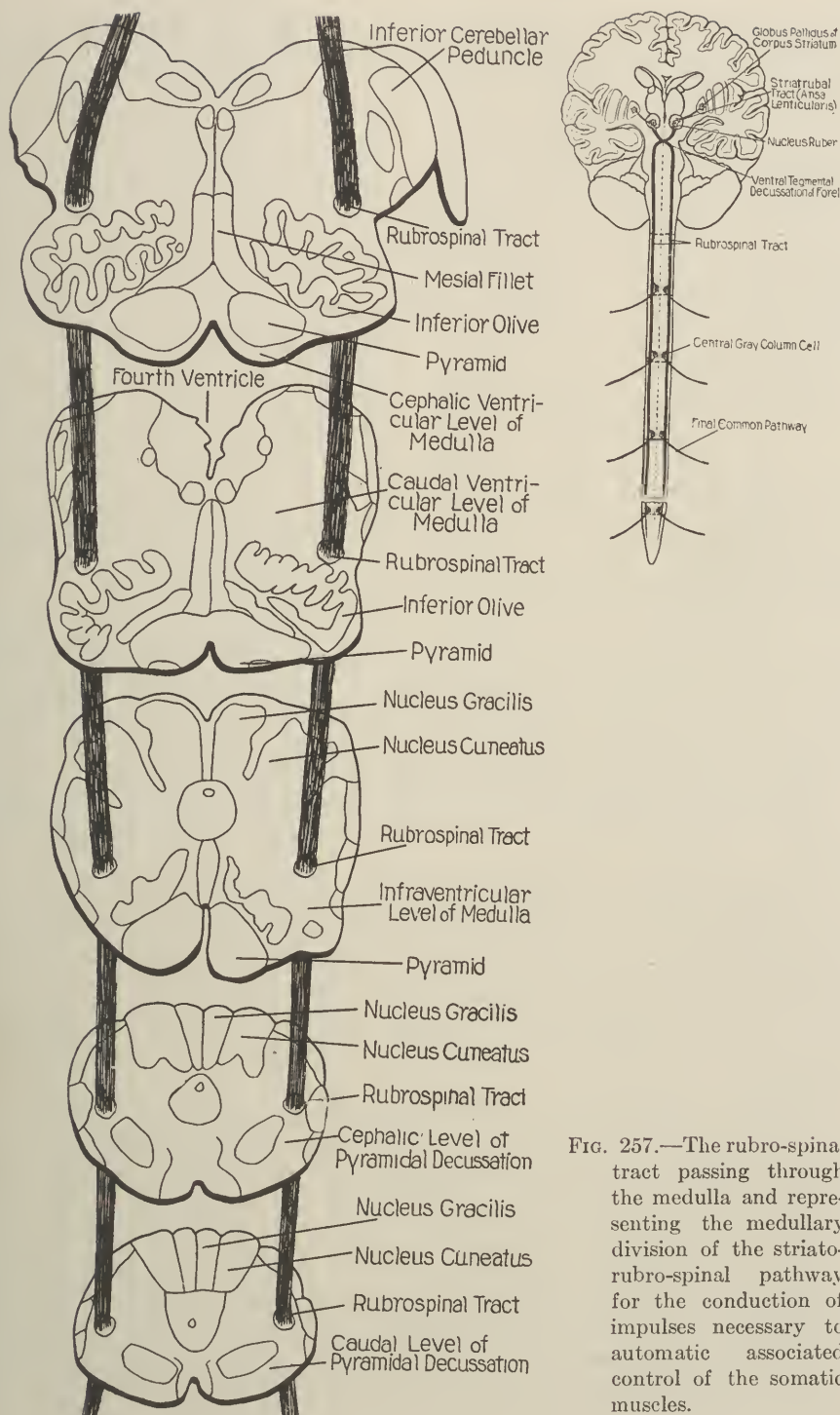


FIG. 257.—The rubro-spinal tract passing through the medulla and representing the medullary division of the striato-rubro-spinal pathway for the conduction of impulses necessary to automatic associated control of the somatic muscles.

mus scriptorius. Flourens called it the *nœud vital*. He believed that the center was situated deep in the reticular formation upon either side of the raphé at the lower angle of the fourth ventricle. Schiff and Girard placed the respiratory center in the *ala cinerea*, while Mislavski located it in a nucleus ventral to the hypoglossal nucleus in the reticular formation. Gad and Marinesco confirmed this general location, while Bechterew placed it in the *formatio reticularis grisea* on either side of the emerging fibers of the twelfth nerve. There is a general consensus of opinion that this respiratory nucleus is situated in the medulla oblongata and in the region of the gray portion of the reticular formation. According to the usual interpretation of the respiratory center, all impulses influencing the principal and accessory muscular mechanisms of respiration are ultimately delivered through this coordinating nucleus of the medulla oblongata. The nucleus not only comes under the immediate influence of reflex activity, but also is controlled from the cerebral cortex by voluntary impulses. By its connection with the sensory elements of the cranial nerves, it responds to stimuli received by the receptors in the mouth, pharynx, larynx and lung, as well as in the nasal passages. It thus furnishes a center which serves to protect the air passages against invasion by deleterious substances.

Chief Source of Stimulation for the Respiratory Center. The venosity of the blood acts as the chief source of stimulation for the respiratory center of the medulla oblongata. The greater the venosity of the blood, the greater is the degree of stimulation carried to the nucleus in the *formatio reticularis grisea*. In addition to such stimulation, certain products of metabolism appear to activate this center, as witnessed in yawning in fatigue.

Other stimuli may affect the respiratory center. This is particularly true of olfactory stimuli received from the first cranial nerve, which cause a distinct reflex respiratory act.

Cutaneous stimuli upon the surface of the face and head determine a reflex expiratory act, followed by deep inspiration.

Stimulation in the sensory area of the glossopharyngeus and vagus nerves is followed by a respiratory reflex movement.

Stimuli from the surface of the body, particularly a sudden application of cold, or stimuli causing pain, result in a deep inspiratory act, followed by expiration.

Auditory stimuli may cause an inhibition of respiratory movement of all types, which probably tends to assist the sense of hearing.

Other Respiratory Acts than Those Immediately Concerned in Respiration. A respiratory act may be so modified as to give rise to phenomena quite different from those of ordinary respiration. Many of these modifications of respiration are simple reflexes, but some are determined by more complex neural associations. Among the modifications of the respiratory act are coughing and sneezing, which have already been referred to as simple reflexes for the purposes of defence of the respiratory tract. Snuffling and other reflex respiratory activities probably belong in the same group. Snoring is a

modification of breathing determined by the fact that in sleep certain changes occur in the upper respiratory passages. The respiratory act may be so modified as to give rise to yawning and sighing, both of which are indicative of changes in metabolism consequent upon fatigue, and produce an increased respiratory effort in order to fill the lung with more than its usual amount of air. Both of these reactions may be regarded as the result of direct stimulation of the respiratory center, and while they are to some extent subject to the influence of the will, they are reflexes in their essential nature. Hiccoughing is another type of modified respiration, occasioned by irritations in the course of the vagus nerve. Here the usual site of irritation is in the gastro-intestinal tract, but the irritant may be located in any part of the vagal distribution. Laughing and crying occasion modifications of respiration, resulting from excitation of the higher centers, particularly those which have to do with the regulation of the emotions.

One type of modified breathing usually regarded as pathological is the *Cheyne-Stokes respiration*. This consists of a regular series of respiratory efforts in crescendo, beginning slowly and regularly with inspiration and expiration, increasing in rate, and depth, and then becoming slower and more shallow until an actual period of apnea is reached. The period of suspended respiration lasts for several seconds, and then the same series of regular, respiratory movements, at first slow, but passing into crescendo, is repeated. The Cheyne-Stokes respiration has been explained as due to a vascular spasm so affecting the respiratory center as to cause exhaustion of it. It should not, however, be regarded necessarily as a pathological clinical phenomenon, because the same type of respiration often occurs in ordinary sleep. Although this is a common symptom of brain disease, it is not due to any known focal lesion.

The Significance of the Vagus Nerve in Respiration. The vagus, which innervates the pulmonary tract with its sensory and motor nerve fibers, acts as a regulator of respiration. It apportions the oxygen intake to the needs of the economy. This may be more graphically expressed in the ratio that the frequency and depth of respiration vary directly with the character and intensity of the stimulus; for example, during sleep the character and intensity of the stimulus are at their minimum, and the frequency and depth of respiration are correspondingly low. In sleep there is low metabolism, and less oxygen is needed; hence there is a less frequent and less deep respiratory movement. In pneumonia, on the other hand, when there is an actual air hunger because of the compromised air space in the lung, the body needs more oxygen and there is a corresponding increase in the frequency and depth of respiration. Another example illustrating this relation of the vagus to respiration is seen in the experimental animal in which both vagi are cut. In the bilaterally vagotomized dog, because the respiratory center is no longer receiving impressions from the lungs, the normal variation in the ratio between the frequency and depth of respiration to the character and intensity of the stimulus is lost. When the vagotomized dog is placed in a chamber in which the air is gradually heated, its respiratory activity does not

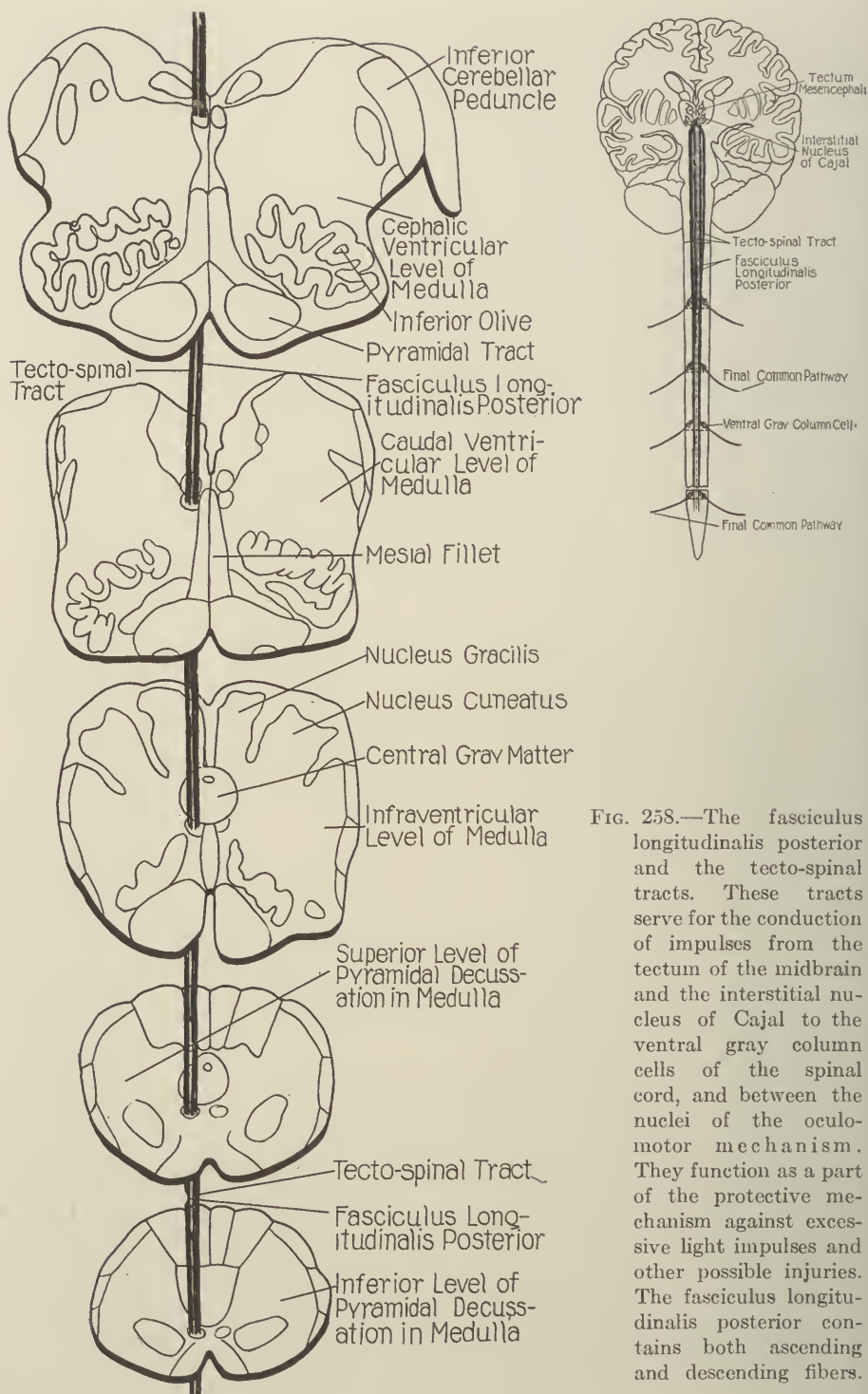


FIG. 258.—The fasciculus longitudinalis posterior and the tecto-spinal tracts. These tracts serve for the conduction of impulses from the tectum of the midbrain and the interstitial nucleus of Cajal to the ventral gray column cells of the spinal cord, and between the nuclei of the oculomotor mechanism. They function as a part of the protective mechanism against excessive light impulses and other possible injuries. The fasciculus longitudinalis posterior contains both ascending and descending fibers.

show the same proportional change as it does in the normal dog. In the normal animal, panting becomes conspicuous with the rise of temperature; undoubtedly due to the fact that the increased amount of heat conveyed in the air serves as a stimulus which causes respiration to deepen and become more frequent. The vagotomized dog has no means of communicating this change in atmospheric heat to his respiratory movement. The vagus in its peripheral pulmonic distribution is largely a receptor responding to mechanical and chemical stimuli, which it transmits first to its primary end stations and then to the nucleus respiratorius. The influence from this nucleus may spread to the entire musculature of the body should the needs of respiration make such demands.

The condition of the blood in the alveolar capillaries may also be active in this reflex. The vagus, through the superior laryngeal nerve, inhibits respiration as a defence against foreign bodies, or determines modifications of respiration, such as coughing, in the interests of the same object. The vagus, therefore, in its relation to the respiratory cycle is a regulator, having especial control over the ratio between the intensity and character of the stimulus on the one hand and the frequency and depth of the respiratory movement on the other. The influence of the will upon respiration is not complete. It is impossible to suppress permanently the respiratory movement. Nevertheless, most of the principal respiratory movements, together with the modifications of respiration, may be imitated at will. Sighing and yawning are slightly more subject to the will than sneezing or coughing, which are difficult to control by volition. Laughing and crying, while essentially reflexes of the emotive sphere, are in part subject to the will. The psychic control of respiration, therefore, is but partial, and is always superseded by the reflex requirements of the economy in the need for oxygen.

THE MEDULLA IN ITS RELATION TO PHONATION. Phonation, the production of the voice, and its highly modified development, speech, depend upon three primary mechanical factors, which are:

1. Increase in the tension of the air in the lung behind the larynx.
2. The narrowing of the rima glottidis by the movements of the vocal cords.
3. Changes in the pharynx and the mouth cavity as well as in the position of the soft palate, jaws, tongue and lips.

The muscles which determine these acts are:

1. The expiratory and inspiratory muscles.
2. The laryngeal muscles.
3. The pharyngeal, palatal, lingual, facial and mandibular muscles.

Special Functions of the Medulla in the Control of the Act of Phonation. The medulla oblongata derives its importance in connection with this mechanism from its control of the larynx, the pharynx and part of the soft palate. In controlling the larynx, it regulates the activity of the following muscles:

1. The adductors of the vocal cords—
 - (a) The thyro-arytenoideus externus;
 - (b) The thyro-arytenoideus internus;

- (c) The thyro-ary-epiglotticus;
- (d) The arytenoideus posticus;
- (e) The crico-arytenoideus lateralis.
- 2. The abductors of the vocal cords—
 - (a) The crico-arytenoideus;
 - (b) The arytenoideus posticus.
- 3. The tensors of the vocal cords—
 - (a) The crico-thyroideus;
 - (b) The genio-hyoideus.

The medulla likewise has control of the muscular groups which serve to increase the pressure of air in the lungs ready for expulsion through the rima glottidis. This is accomplished through the respiratory center. The larynx is supplied by the recurrent laryngeal nerve, which innervates all of the muscles except the crico-thyroid, the latter being supplied by the superior laryngeal nerve. The medulla, furthermore, innervates the pharynx, the palate, the tongue and, in part, the lips, in the acts performed by these structures in phonation. A center for phonation is in all probability located in the nucleus ambiguus in the medulla oblongata.

THE MEDULLA OBLONGATA IN ITS RELATION TO DEGLUTITION AND DIGESTION. Deglutition is a complex act having the following phases, or series of movements:

The first series of active factors results in grasping the bolus through movements of the jaws, of the tongue, of the lips and of the cheeks. The activity of the jaws is controlled by the motor division of the fifth cranial nerve, whose nucleus is situated in the pons Varolii. The movements of the tongue are controlled by the hypoglossal nerve, whose nucleus is in the medulla. The lips and cheeks are controlled by the seventh nerve, whose nucleus is in part in the medulla, but mainly in the pons.

The second series of movements in deglutition results in the introduction of the bolus into the fauces. This is determined by the combined action of all of the muscle groups participating in the first phase, obliterating the mouth cavity. By pressure of the tongue upon the hard palate, closure of the jaw and compression of the lips and cheeks, the bolus is forced into the isthmus of the fauces.

The third series of movements results in the closure of the posterior nares to prevent the regurgitation of food or fluid through the nose. This is accomplished by the elevation of the soft palate, which acts as a valve to close off the orifice of the posterior nares. These muscles acting in this capacity are supplied by the ninth and tenth cranial nerves, and have their nuclei in the medulla oblongata.

The fourth phase of deglutition depends upon the closure and elevation of the larynx, with the object of preventing the entrance of food or fluid into the air passages and also of opening wider the upper orifice of the gastrointestinal canal. The action of the mylohyoid and digastric muscles, causes the larynx to be drawn forward and upward, while the closure of the larynx is accomplished by the epiglottis and the partial approximation of the vocal

cords. The muscles causing the elevation and forward movement of the larynx are supplied by the fifth and seventh cranial nerves, part of the motor

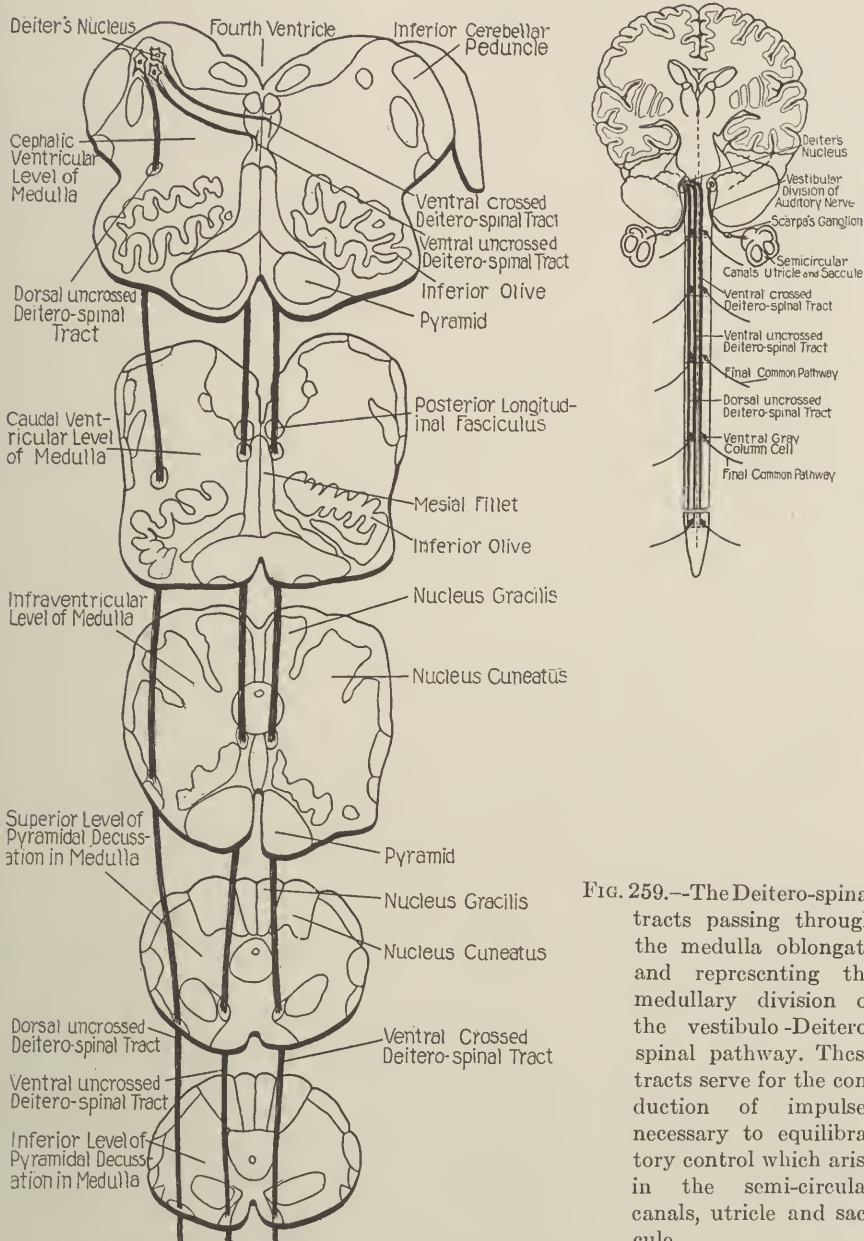


FIG. 259.—The Deitero-spinal tracts passing through the medulla oblongata and representing the medullary division of the vestibulo-Deitero-spinal pathway. These tracts serve for the conduction of impulses necessary to equilibratory control which arise in the semi-circular canals, utricle and sacculle.

nucleus of the latter being situated in the medulla. The vagus innervates the muscles producing the valve-like changes in the epiglottis and the vocal cords, and has its center of control entirely in the medulla.

The grasp of the bolus by the pharynx takes place as a result of the contraction of the constrictor muscles of the pharynx. These muscles are innervated by the glossopharyngeal nerve, which has its origin in the medulla.

Deglutition is completed by the longitudinal and circular muscle layers of the esophagus, which are innervated by the vagus.

The control of deglutition is vested in the medulla oblongata, with the exception of such movements as are necessary for the closure of the jaw, the occlusion of the lips, and the elevation and forward traction of the larynx. These elements of deglutition are innervated by the seventh and fifth cranial nerves, and thus have their main centers in the next higher division of the brain-stem, the pons Varolii. The greater part of the act of deglutition is reflex. Its first phase is completely under the control of the will, both in its initiation and its completion. Once the bolus of food or the fluid has passed through the isthmus of the fauces, the act of deglutition becomes reflex and free from regulation by the will.

The Muscular Activities of Digestion. The muscular movements necessary for the digestion of food are dependent upon influences derived from the medulla. These influences reach the musculature in the walls of the stomach and intestine by means of the vagus nerve. The stomach and intestine are also supplied with motor impulses from the sympathetic system, and this dual innervation acts in a mutualistic synergy, producing the movements of the gut tract most effectual in preparing the food for the chemical processes of digestion and assimilation. In the muscular act of digestion, the stomach presents three distinct divisions, each acting in a somewhat different manner:

The first portion is the *cardia*, which serves as a receptacle and as a valve preventing the regurgitation of the food into the upper food passages. Its muscular activity is in part peristaltic and in part constrictive, since it must give resistance to the active tritulatory movements which produce the necessary division of the food stuffs.

The second portion is the *fundus*, in which the action is rotato-tritulatory and carried on as a constant and regular peristalsis, especially during the presence of food in the stomach.

The third portion is the *pylorus*, in which the muscular activity is rhythmically peristaltic at more or less regular intervals, its object being to further the emptying of the stomach into the duodenum. It also guards the portal of the intestinal canal in such a way as to prevent the passage of food in the process of digestion until it is properly prepared for the action of the small intestine. At regular intervals, the gastric contents accumulated by means of rhythmical peristalsis are propelled into the duodenum ready for further treatment in the intestinal canal.

All three parts of the stomach, acting in these different capacities, receive a dual innervation through the vagus and the sympathetic system. For the cardia, the vagus contains fibers which serve both as inhibitors and accelerators. These axones have their origin in the dorsal motor nucleus

of the vagus. The sympathetic system is a synergist of the vagus in all of these activities of the cardia. The innervation of the fundus and pylorus corresponds in all respects to that of the cardia, so that the stomach receives part of its dual innervation through the vagus nerve from the dorsal motor nucleus of that nerve in the medulla.

The muscular activity of the intestine depends upon the circular and longitudinal musculature of the intestinal canal, which is innervated in a manner similar to that of the stomach, except that in this case the vagus acts much more as an excitor to peristalsis, while the sympathetic, according to most authorities, acts as an inhibitor.

THE MEDULLA OBLONGATA IN ITS RELATION TO CARDIAC ACTION. The heart is innervated by a triple nerve supply: first, an intrinsic innervation from the ganglia of the heart; second, through the sympathetic system; and third, through the vagus. The vagus acts as an inhibitor of cardiac action. Stimulation of the peripheral ends of the cut vagi slows the heart, and if the stimulation be strong enough, will bring it to a standstill in diastole. The center for this inhibitory control of the cardiac cycle is situated in the dorsal motor nucleus of the vagus nerve. The medulla oblongata, although it is not the sole regulator of heart action, plays an important rôle in the energizing of systole and in sparing the heart from the fatigue which would naturally ensue were it left free to pulsate under the influence of its intrinsic ganglia and the sympathetic system. Without this inhibitory control of the vagus, cardiac activity would present the phenomenon known as "*runaway heart*."

THE MEDULLA OBLONGATA IN ITS RELATION TO METABOLISM, ESPECIALLY TO GLYCOMETABOLIC CONTROL. It has long been known that glycosuria may be produced by a small puncture of the floor of the fourth ventricle between the nuclei of the eighth and tenth nerves. From this fact it has been argued that there is a glycometabolic center situated in the medulla oblongata. Injury of this part of the brain sometimes results in a pronounced glycosuria. This pathological condition is probably due to irritation of the vagus nucleus controlling the glandular effector fibers which innervate the liver and the pancreas. Such stimulation might easily lead to an excessive mobilization of glycogen with a corresponding hyperglycemia and glycosuria.

THE MEDULLA OBLONGATA IN ITS RELATION TO SECRETION. Experimental evidence has demonstrated that the medulla has control over salivary, gastric, pancreatic, intestinal, biliary, lachrymal and sudorific glandular activity. By means of fibers arising in the nucleus salivatorius inferior, the medulla exerts an influence upon the secretion of saliva. The salivary glands receive impulses from three sources: first, the inferior salivary nucleus, whose fibers are conveyed by the vagus nerve; second, the superior salivary nucleus, whose fibers arise in the trigeminal nerve; and third, the sympathetic system. Glandular effector fibers arising in the medulla and making their way into the stomach by means of the vagus

nerve cause an increase in the secretion of gastric juice, as a result of both reflex and psychic stimuli. The vagus exerts a strong stimulating influence over the pancreatic and biliary secretions, independent of circulatory changes. The center for the control of this secretory activity is in the dorsal vagus nucleus. The secretion of mucus throughout the gastro-intestinal tract is dependent upon a dual innervation, in part derived from the vagus, and in part from the sympathetic system.

Sudoriferous secretion for the head is carried on under the influence of a center situated in the reticular formation beneath the floor of the fourth ventricle. The more exact localization of this center has yet to be determined, but clinical material abundantly justifies the idea that such a center exists in the tegmental portion of the medulla. The fibers mediating the influences which control the sweat glands of the head probably make their way to the glands by means of the facial and trigeminal nerves.

THE FUNCTIONS OF THE WHITE MATTER IN THE MEDULLA OBLONGATA

The medulla affords continuity in the conduction paths whose integral tracts arise lower down and pass upward, or arising at higher levels descend into the spinal cord.

Descending Tracts Traversing the Medulla. The *pallio-spinal pathway* for volitional control passes through the medulla without interruption. This tract is the upper motor neurone element in the pathway leading from the cortex to the spinal cord and bulb, and thence to the skeletal muscles. It mediates influences of volitional control.

The *tecto-spinal tract*, which arises in the tectum of the mid-brain, also descends through the medulla oblongata, in the more cephalic portion of which it is incorporated with the fasciculus longitudinalis posterior. In the caudal extremity of the medulla, the tecto-spinal tract moves into a more ventral position, from which it passes into its usual spinal cord position in the ventral white column. This tract transmits impulses which arise in the suprasegmental portion of the midbrain, the tectum, to the spinal cord and thus to the muscles. It is presumed that it is connected in some way with the transmission of impulses related to the perception of light, and is probably concerned with the production of defence mechanisms for the protection of the eye by means of the upper extremity.

The *rubro-spinal tract* is an intersegmental connection which passes through the medulla without crossing, and serves for the transmission of impulses which have to do with synergic and associated automatic control.

The *Deitero-spinal tract* is another intersegmental fasciculus connecting the nucleus of Deiters with the various levels of the spinal cord, and transmitting impulses which have to do with equilibratory control. The two Deitero-spinal tracts pass through the medulla, the ventral tract partially crossing in it, while the lateral tract remains uncrossed throughout its entire extent.

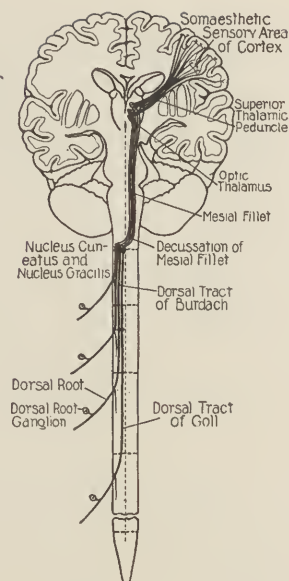
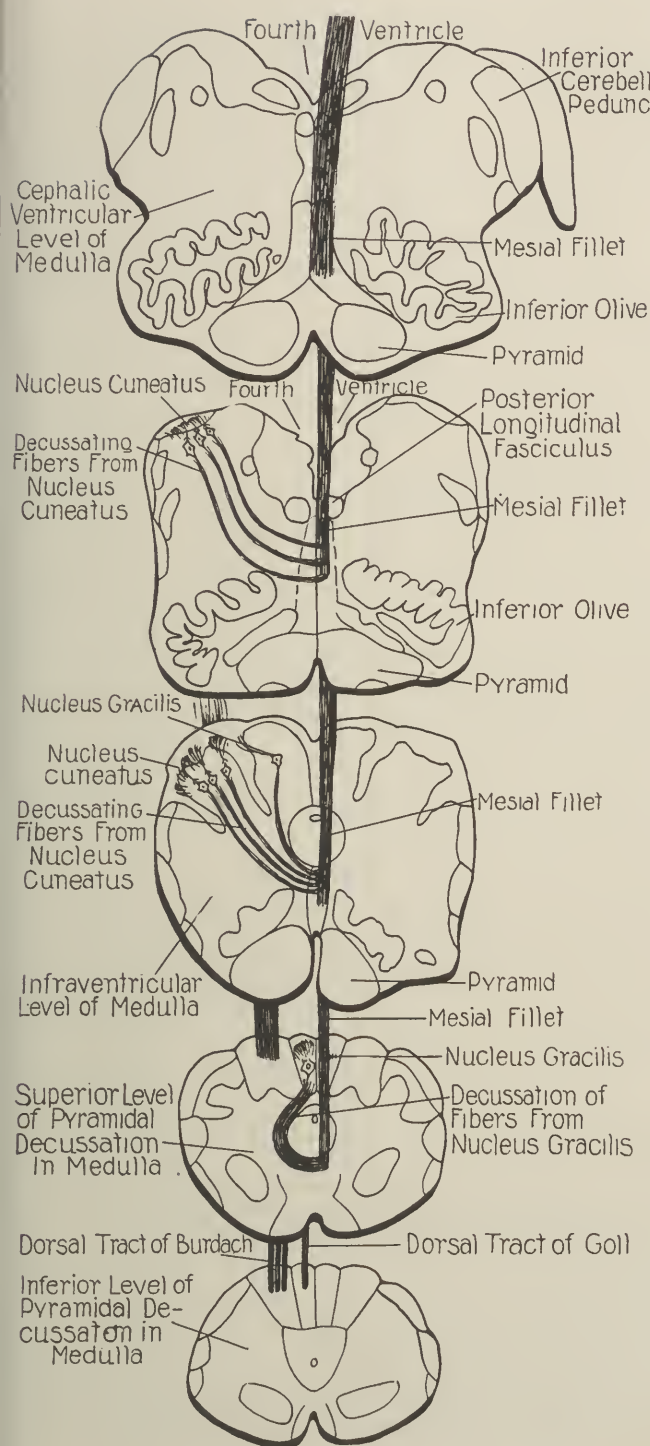


FIG. 260.—Continuation of the dorsal tracts of Goll and Burdach into the medulla. These tracts are relayed in the nucleus cuneatus and nucleus gracilis. The secondary tracts resulting from this synapse undergo decussation and form the mesial or bulbar fillet which serves chiefly for the conduction of discriminative somesthetic impulses from the skin, muscles, joints and bones.

The *olivo-spinal tract* likewise represents an intersegmental connection, which brings the inferior olive into relation with the upper cervical segments of the spinal cord, and coordinates the movements of the eyes and head.

The *central tegmental tract* is an intersegmental connection which associates the nuclei of the third, fourth and sixth cranial nerves with the inferior olives, and thus acts as a connecting link in the mechanism which determines coordinative control of the head and eye movements.

The *fasciculus longitudinalis dorsalis* of Schütz is a long intersegmental descending tract which has its origin in the midbrain. It represents the vestige of an old motor pathway in the neuraxis.

The *reticular formation*, especially the white portion, is an important descending association system which connects the respiratory nucleus of the medulla oblongata with the motor cells in the cervical and thoracic segments of the spinal cord, and serves to bring the respiratory muscles under the direct control of the principal coordinating respiratory center in the brain.

Ascending Tracts Traversing the Medulla. Through the medulla passes the *mesial fillet* (mesial lemniscus) which is the continuation of the columns of Goll and Burdach. In addition to the fibers of the mesial fillet, there are ascending axones from the substantia gelatinosa. These are ascending trigeminal fibers which pass through the medulla as the second neurone in the sensory pathway from the head and face.

The *spino-thalamic tract* passes through the medulla without interruption or crossing; it has already undergone decussation in the spinal cord. This tract is sometimes spoken of as the *spinal fillet* in contradistinction to the mesial fillet, which is referred to as the *bulbar fillet*. The spino-thalamic tract serves for the conveyance of pain and temperature impulses from the opposite side of the body.

Another group of ascending fibers which pass through the medulla are the *dorsal* and *ventral spino-cerebellar tracts*. These are elements in the pathway from the muscles to the cerebellum. The dorsal spino-cerebellar tract of Flechsig becomes incorporated in the inferior cerebellar peduncle. The ventral spino-cerebellar tract does not enter into this peduncle, but passes directly to the next higher segment of the brain. These two tracts are suprasegmental, because they bring the segmented portions of the nervous system into connection with a suprasegmental structure, the cerebellum.

The *posterior longitudinal fasciculus* serves to bring into coordinative relation the several nuclei in the mechanism of ocular movement. It also brings these nuclei into relation with the vestibular division of the eighth nerve, and thus under the influence of the semicircular canals.

The Principal Decussations in the Medulla. Six pathways undergo decussation in the medulla:

1. The pallio-spinal pathway for volitional control.
2. The spino-thalamo-pallial pathway for discriminative sensibility. This is the decussation of the bulbar or mesial fillet.
3. The olivo-cerebellar pathway. This decussation is the inferior olivary crossing.

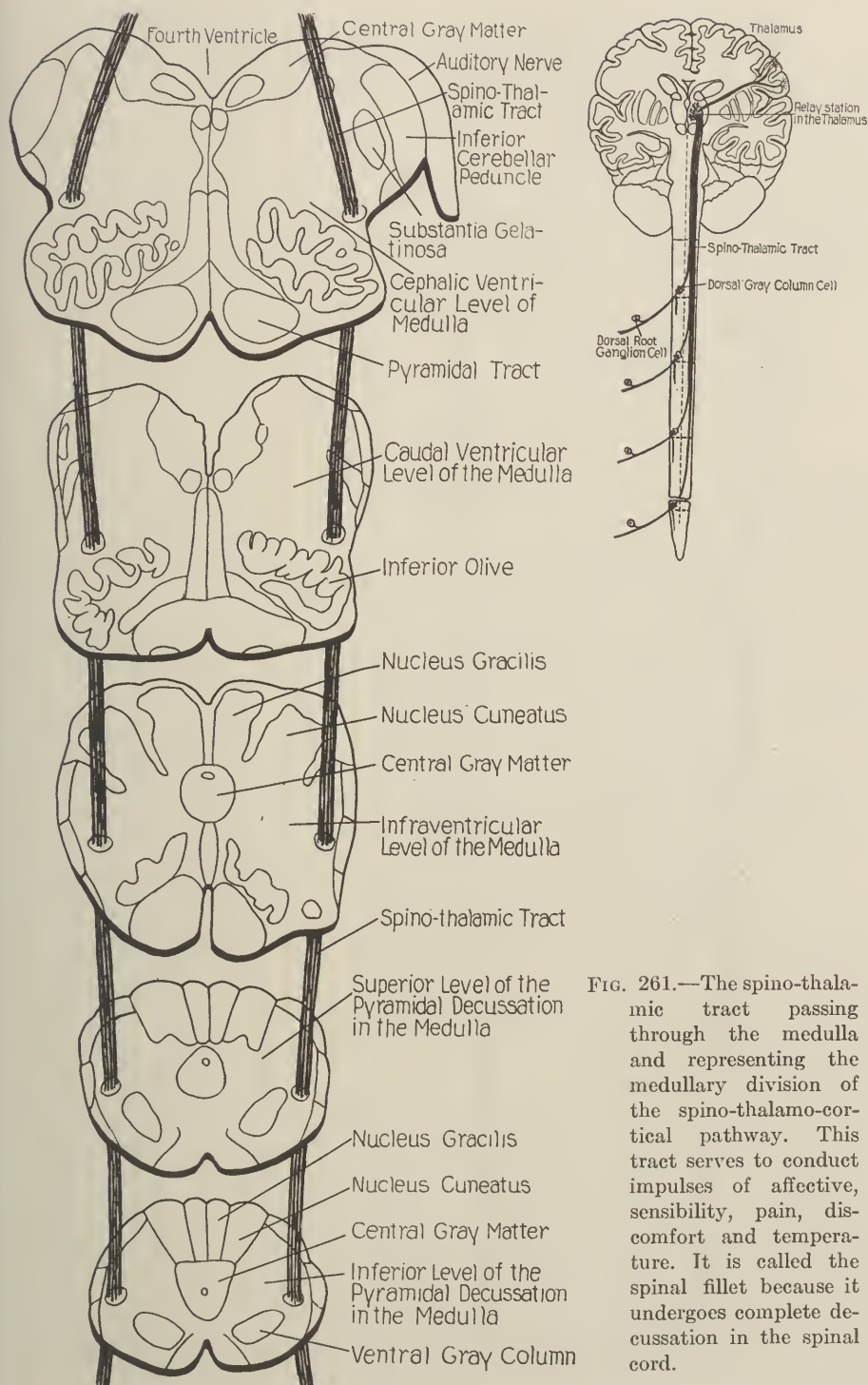


FIG. 261.—The spino-thalamic tract passing through the medulla and representing the medullary division of the spino-thalamo-cortical pathway. This tract serves to conduct impulses of affective, sensibility, pain, discomfort and temperature. It is called the spinal fillet because it undergoes complete decussation in the spinal cord.

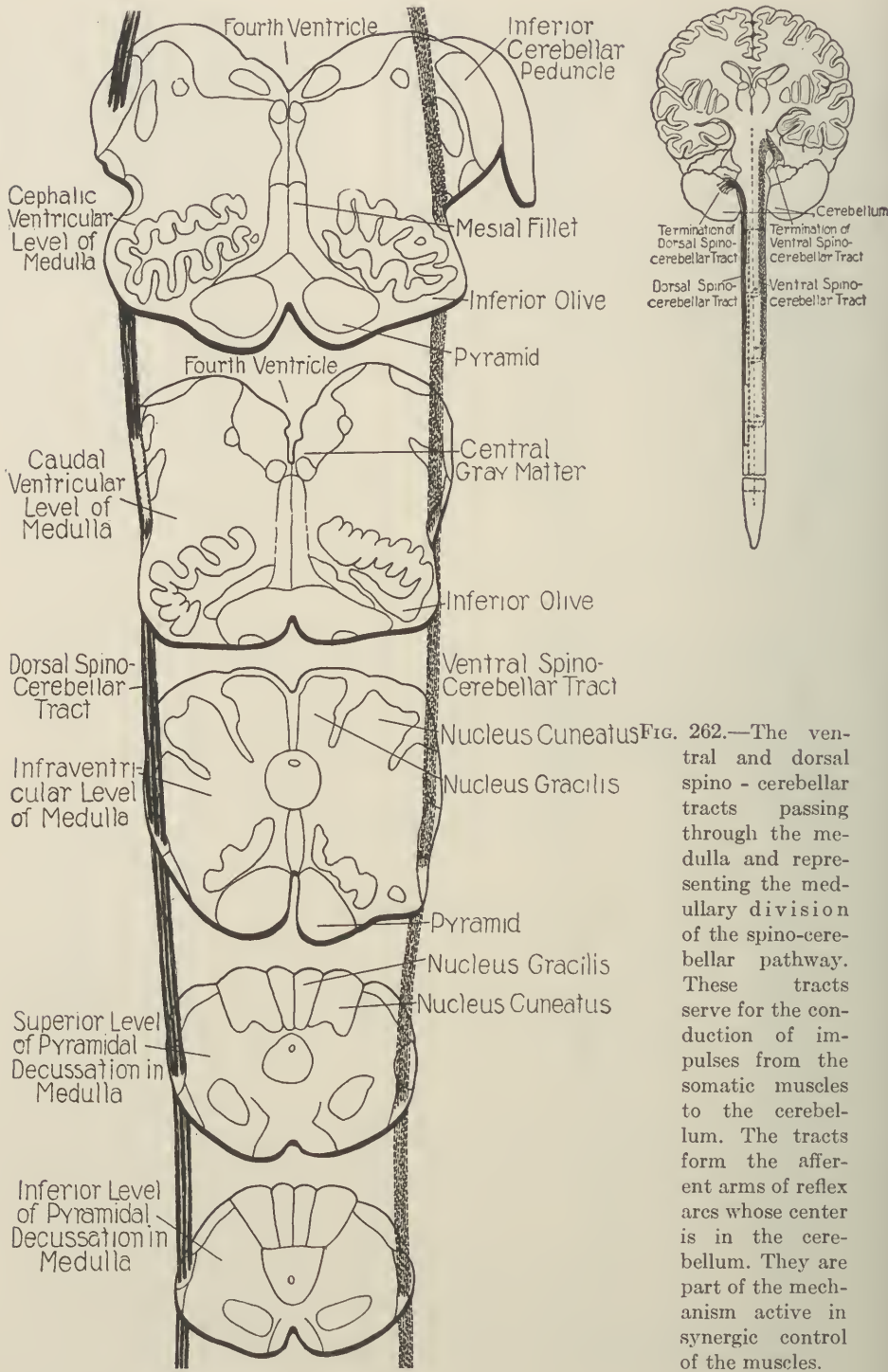


FIG. 262.—The ventral and dorsal spino - cerebellar tracts passing through the medulla and representing the medullary division of the spino-cerebellar pathway. These tracts serve for the conduction of impulses from the somatic muscles to the cerebellum. The tracts form the afferent arms of reflex arcs whose center is in the cerebellum. They are part of the mechanism active in synergic control of the muscles.

4. The spino-cerebellar pathway which undergoes a partial crossing by means of the ventral and dorsal external arcuate fibers.

5. The trigeminal pathway, the decussation of which provides a complete crossing for all types of sensibility from the regions of the head, face and cavities of the head.

6. The Deiteral pathway, the decussation of which consists of a partial crossing of the fibers arising in Deiters' nucleus and entering either the fasciculus longitudinalis posterior or the ventral Deitero-spinal tract.

Summary of the Functions of the Medulla Oblongata. The functions of the medulla oblongata may be summarized briefly as follows:

The *gray matter* of the medulla represents a dominant autonomy over the vital processes of life. It mediates an essential control over respiration, cardiovascular activity, phonation, articulation, deglutition, digestion, secretion and metabolism. It also acts as an important relay station for both divisions of the auditory nerve.

The *white matter* of the medulla represents the continuity in all of the major conduction paths which serve to maintain efficient relations between the receptors and effectors of the body. Not only is the medulla traversed by many of the most important afferent and efferent pathways of the nervous system, but it is also the site of decussation of several conduction systems, notably the mesial fillet, Deitero-spinal, olivo-cerebellar and pyramidal tracts.

CHAPTER XIX

THE MEDULLA OBLONGATA

PRINCIPAL SYNDROMES OF THE MEDULLA

In consequence of its marked rearrangements, it is impossible to describe the syndromes of the medulla as those affecting the gray matter or the white matter separately. Usually some part of both of these elements is involved by the lesion. The syndromes of this part of the brain-stem are most conveniently designated by the chief structures implicated by the pathological process. This method will be employed in the following descriptions. Not all of the symptom-complexes which may arise in connection with disease of the medulla will be discussed, but rather those most illustrative of the functional possibilities in the light of anatomical relations.

Syndrome of the Pyramidal Decussation. **HISTORY.** A young man, as the result of diving, received an injury to the head and was unconscious for ten hours. Upon regaining consciousness, it was found that he had a paralysis of the right arm and left leg. He could not move his left foot, leg or thigh, nor was there any voluntary control over the right hand, forearm or arm. Other parts of the body were normal. In the course of several days the right arm and left leg became rigid, and he suffered from a spastic paralysis in the parts affected. This condition, gradually improving, persisted for a year, when the patient died of pneumonia.

EXAMINATION. *Somatic Motor Component.* The idiodynamic control of the affected arm and leg was normal. The reflexes in the right arm were more active than the left arm, while the reflexes in the left leg not only showed an increase as compared with those of the right leg, but certain pathological reflexes were also present, as the Babinski, crossed periosteal, ankle and patellar clonus. The muscle tone of the right arm was increased to such a degree as to determine a malposition of the fingers, which were held in flexion, and of the forearm, which was drawn up with a slight degree of flexion at the elbow. There was an increase in tone of the left leg as compared with the tone of the right leg. At the time of the examination, there was a complete loss of volitional control in the right arm and left leg, the left arm and right leg being normally under the control of the will. Synergic control in the affected parts could not be determined because of the marked degree of spastic paralysis. Equilibratory control was normal in the unaffected parts, but could not be estimated in the paralyzed members. All of the cranial nerves were normal.

The Somatic Sensory Component. This component showed no disturbance in any type of somatic sensibility.

The *splanchnic motor* and *splanchnic sensory components* likewise were normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The sudden appearance of symptoms following an injury and attended by unconsciousness indicates the traumatic nature of the lesion which, in all probability, caused a hemorrhage in the central nervous system.

The evidence of the focus of the lesion points conclusively to involvement of the pyramidal tracts, and the only position in which these tracts could be simultaneously involved in such a way as to effect a paralysis of an arm and the opposite leg is in the pyramidal decussation at a level in which the arm fibers have already made their crossing and the leg fibers in the pyramidal system are about to decussate.

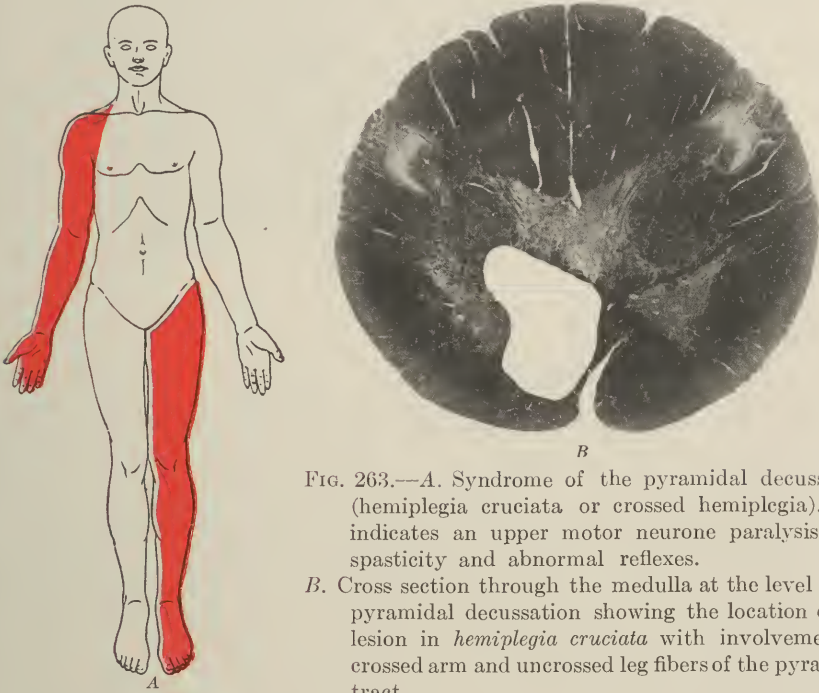


FIG. 263.—A. Syndrome of the pyramidal decussation (hemiplegia cruciata or crossed hemiplegia). Red indicates an upper motor neurone paralysis with spasticity and abnormal reflexes.
B. Cross section through the medulla at the level of the pyramidal decussation showing the location of the lesion in *hemiplegia cruciata* with involvement of crossed arm and uncrossed leg fibers of the pyramidal tract.

The evidence of circumscription of the lesion is to be found in the absence of all other motor and sensory disorders, thus limiting the area of involvement exclusively to the pyramidal decussation.

DIAGNOSIS AND PATHOLOGY. This condition is due to trauma affecting the pyramidal decussation, and probably giving rise to a hemorrhage in this part of the medulla.

NOMENCLATURE. This syndrome is known as *hemiplegia cruciata* or *crossed hemiplegia*.

VARIATIONS. If the lesion is extensive enough to involve all the bundles of decussating fibers, the resulting paralysis is a spastic tetraplegia, including all four extremities.

SUMMARY. The essential clinical features of this syndrome are:

1. Crossed hemiplegia, involving an arm and the opposite leg.
2. Upper motor neurone type of paralysis with increased and pathological reflexes and increased muscle tone.
3. The appearance of abnormal associated movements in the paralyzed parts.
4. The absence of all sensory and splanchnic symptoms, and the absence of any symptoms referable to the cranial nerves.

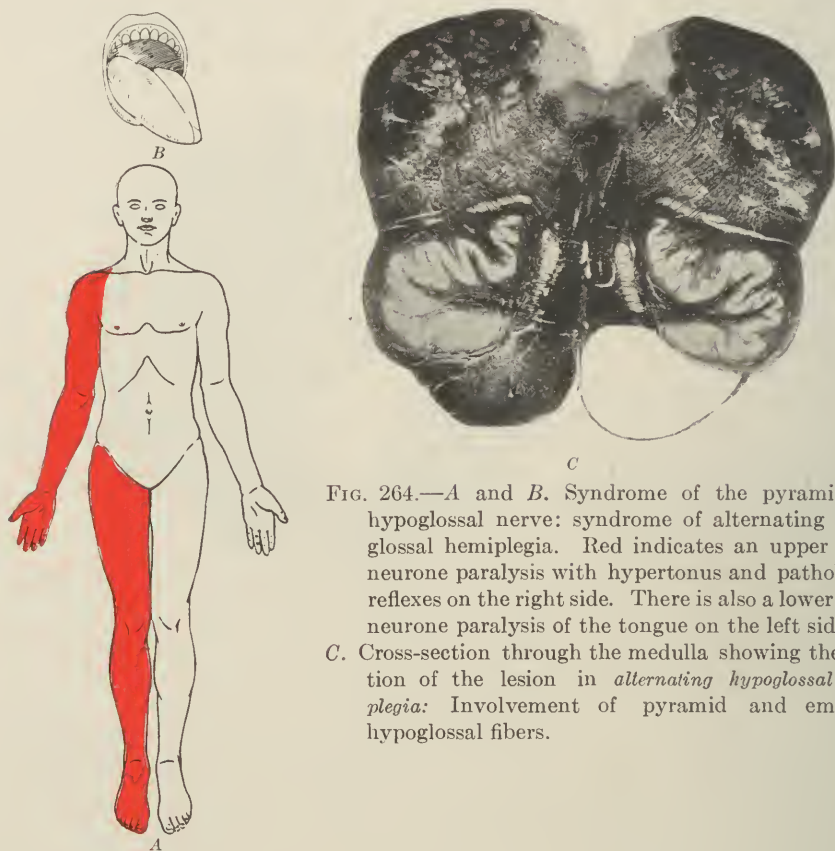


FIG. 264.—A and B. Syndrome of the pyramid and hypoglossal nerve: syndrome of alternating hypoglossal hemiplegia. Red indicates an upper motor neurone paralysis with hypertonus and pathological reflexes on the right side. There is also a lower motor neurone paralysis of the tongue on the left side. C. Cross-section through the medulla showing the location of the lesion in *alternating hypoglossal hemiplegia*: Involvement of pyramid and emergent hypoglossal fibers.

Syndrome of the Pyramid and the Hypoglossal Nerve. HISTORY. A man, fifty-three years old, while at business, was suddenly seized with a fainting spell which lasted several minutes. Upon regaining consciousness, he felt weak and could neither speak nor move his right arm or leg. After several days his speech returned, although he was conscious of difficulty in moving his tongue. His right arm and leg remained paralyzed and gradually became rigid. He remained in this general condition until the end of his life, which followed two years later in consequence of a severe apoplectic seizure.

EXAMINATION. *The somatic motor component* showed a complete paralysis of the right arm and leg with a paralysis and atrophy of the left side of the tongue. The idiodynamic control of the right arm and leg was normal. The reflexes were all increased on this side of the body, the Babinski, the patellar and ankle clonus being present. The reflexes of the left side of the body were normal. Volitional control was lost on the right side, including the right arm and leg, while synergic and equilibratory control could not be estimated on account of the extreme degree of spastic paralysis. Abnormal associated movements were present in the right arm and leg, but were not observed upon the left side of the body. Of the cranial nerves, the hypoglossal showed a distinct lower motor neurone type of paralysis upon the left side, the right side being normal. The tongue presented the appearance upon the left side of many corrugations along its border, and when protruded, the tip turned to the left.

The somatic sensory, splanchnic motor and splanchnic sensory components were all normal.

The patient ran a constantly high blood pressure, ranging from 200 to 220 mm. of Hg.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion was due to a vascular accident, probably a hemorrhage. This supposition was borne out by the sustained high blood pressure and the terminal apoplectic seizure.

The evidence of the focus of the lesion indicates some site where the pyramidal tract and hypoglossal nerve may be simultaneously involved. The most likely position for such an involvement is the point where the emergent root fibers from the hypoglossal nerve come into relation with the pyramidal tract in the medulla oblongata. The lesion, therefore, is situated on the left side involving the left pyramid and the left hypoglossal nerve. The pyramidal fibers subsequently decussate, which explains the paralysis of the right arm and leg, while the left side of the tongue is affected.

The evidence of circumscription of the lesion is afforded by the absence of all symptoms referable to other motor functions, as well as the absence of somatic sensory, splanchnic motor and splanchnic sensory disturbances.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is hemorrhage into the medulla oblongata at the level of the pyramid upon the left side.

NOMENCLATURE. This syndrome is known as *hypoglossal alternating hemiplegia* or *hemiplegia alternans hypoglossica*.

VARIATIONS. In some cases the lesion may extend across the midline and involve the opposite pyramid. When such is the case, all four extremities will show some degree of paralysis.

SUMMARY. The essential clinical features in the syndrome of hypoglossal alternating hemiplegia are:

1. An upper motor neurone paralysis involving the arm and leg, with increased tone, pathological reflexes, and abnormal associated movements contralateral to the lesion.

2. Ipsilateral lower motor neurone paralysis of the tongue with loss of idiodynamic control, as indicated by the atrophy.

4. No somatic sensory or splanchnic disturbances of any kind.

Syndrome of the Mesial Fillet, Pyramid and Hypoglossal Nerve.

HISTORY. A young woman during convalescence from a severe attack of typhoid fever, began to notice the gradual loss of power in her right arm and leg, together with some loss of sensation in the same region. All other parts of the body were apparently normal. After the lapse of two months

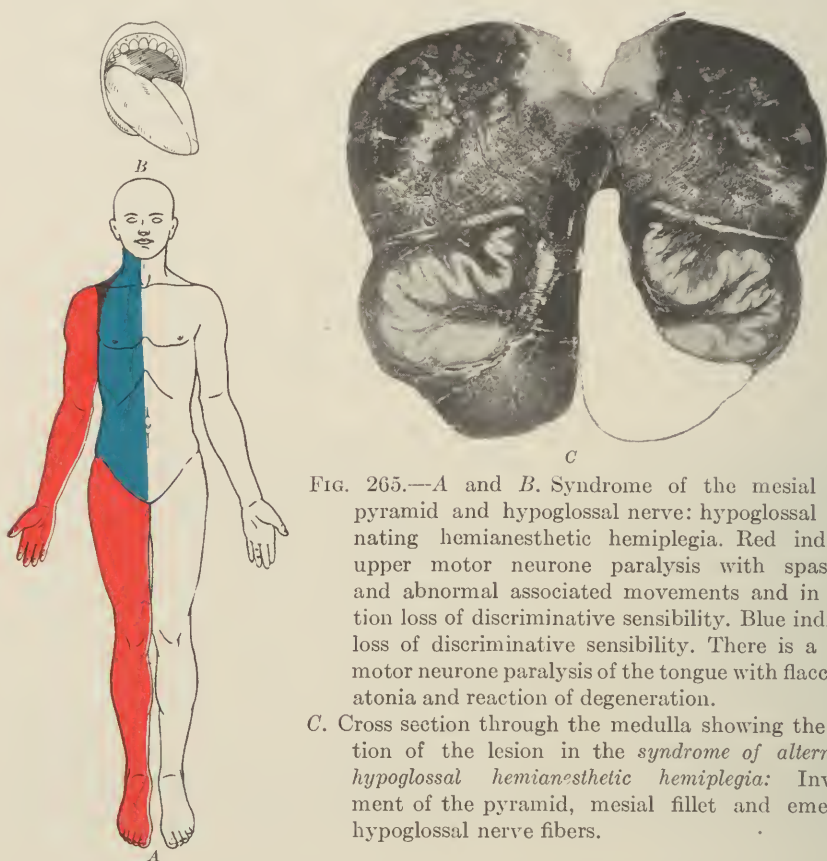


FIG. 265.—A and B. Syndrome of the mesial fillet, pyramid and hypoglossal nerve: hypoglossal alternating hemianesthetic hemiplegia. Red indicates upper motor neurone paralysis with spasticity and abnormal associated movements and in addition loss of discriminative sensibility. Blue indicates loss of discriminative sensibility. There is a lower motor neurone paralysis of the tongue with flaccidity, atonia and reaction of degeneration.

C. Cross section through the medulla showing the location of the lesion in the *syndrome of alternating hypoglossal hemianesthetic hemiplegia*: Involvement of the pyramid, mesial fillet and emergent hypoglossal nerve fibers.

she became completely paralyzed in the right arm and leg, and had lost all powers of discrimination in muscular and cutaneous sense in these parts. She remained in this condition until her death, which occurred five years later from pneumonia.

EXAMINATION. Somatic Motor Component. The idiodynamic control of the entire body with the exception of the left side of the tongue was normal. There was marked atrophy and lower motor neurone paralysis of the left side of the tongue. The reflexes and muscle tone of the right arm and leg were much increased; there was a Babinski on the right side, a patel-

lar and ankle clonus and a crossed periosteal reflex. The tone in the right arm and leg was so much increased that these extremities were held in a rigidly fixed, abnormal position. The volitional control over the right arm and leg was almost completely lost. Equilibratory and synergic control could not be estimated because of the spastic paralysis which masked all movements. Abnormal associated movements were present in the upper and lower extremities on the right side. The tongue showed a flaccid paralysis and atrophy on the left side. The other cranial nerves were normal.

Somatic Sensory Component. This component showed a complete loss of discriminative sensibility in the right arm and leg, particularly discerned in defective muscle, joint and vibratory sense, as well as tactile discrimination in the parts mentioned. Somatic sensibility was normal in all other parts of the body.

The *splanchnic motor* and *splanchnic sensory components* were normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The pathological process producing the symptoms was a vascular accident, probably thrombosis, as this lesion is not infrequent as a consequence of typhoid fever.

The evidence of the focus of the lesion points to a locality in which the discriminative sensory pathway, the pyramidal tract and the twelfth nerve might be simultaneously involved. The medulla oblongata is the only portion of the brain where these structures are in proximity; in fact, all three are in contiguity in the medulla, the pyramid lying ventral to the fillet and the emergent root fibers lying lateral to both, so that a lesion affecting this region would produce a hemianesthesia in discriminative sensibility on the opposite side, and an upper motor neurone spastic paralysis on the opposite side with a lower motor neurone paralysis of the tongue upon the same side.

The evidence of circumscription of the lesion is found in the absence of other motor symptoms, and the fact that the pain-temperature pathway shows no involvement and that no special sense is affected. The absence of any splanchnic motor or sensory symptoms further aids in the circumscription of the lesion.

DIAGNOSIS AND PATHOLOGY. This clinical condition is due to thrombosis of a branch of the anterior spinal artery, which causes a degenerative process in the mesial fillet and pyramidal tract on the left side, and also in the emergent root fibers of the left twelfth cranial nerve.

NOMENCLATURE. This syndrome is known as *hypoglossal alternating hemianesthetic hemiplegia*.

VARIATIONS. As in the previous case, the lesion may extend across the mid-line, when both fillets and both pyramidal tracts would be involved. This would lead to disturbances in sensation and voluntary control on both sides of the body.

SUMMARY. The essential clinical features of this syndrome are:

1. Spastic paralysis, with increased reflexes and muscle tone and abnormal associated movements contralateral to the lesion.
2. Loss of discriminative sensibility in the right arm and leg and right

side of the body up to the dorso-median and ventro-median lines contralateral to the lesion.

3. The normal status of affective sensibility (including pain and temperature).

4. The ipsilateral lower motor neurone paralysis of the tongue accompanied by atrophy.

5. The absence of all other motor or sensory disturbances, and the absence of splanchnic motor and sensory symptoms.

The Syndrome of the Nucleus Ambiguus and Nucleus Accessorius.

HISTORY. A child, three years old, began to have difficulty in swallowing. This was attended by regurgitation of fluids through the nose. The voice

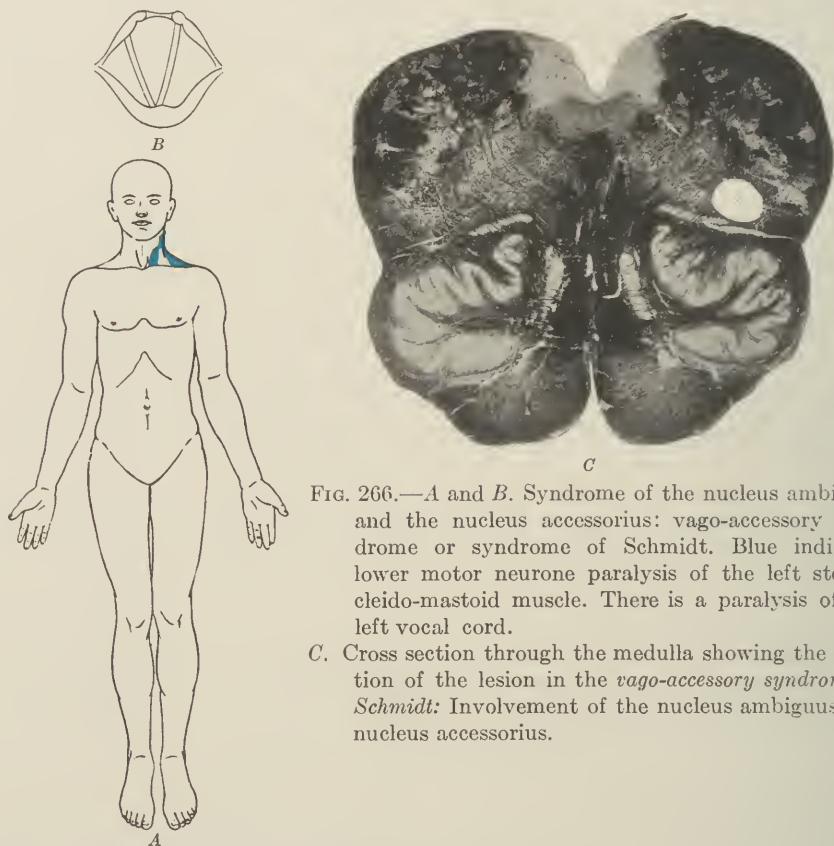


FIG. 266.—A and B. Syndrome of the nucleus ambiguus and the nucleus accessorius: vago-accessory syndrome or syndrome of Schmidt. Blue indicates lower motor neurone paralysis of the left sterno-cleido-mastoid muscle. There is a paralysis of the left vocal cord.

C. Cross section through the medulla showing the location of the lesion in the *vago-accessory syndrome of Schmidt*: Involvement of the nucleus ambiguus and nucleus accessorius.

became hoarse. The head was held with the chin turned toward the left. The child could not turn her head toward the right. At the end of four months the patient had a terminal convulsion, preceded by several hours of increasing dyspnea, and died. There was a history of tuberculosis in the family, the mother and an older sister having died of this disease. The patient ran a low temperature for several months, and toward the end of her sickness

the temperature gradually rose. The von Pirquet test was positive; the Wassermann test upon the blood was negative.

EXAMINATION. The *somatic motor component* showed that the idiodynamic control, the reflex and tonic control, volitional control, equilibratory, synergic and automatic associated control of all parts of the body were normal.

The *somatic sensory component* showed no disturbance of any type.

The *splanchnic motor component* showed a distinct paralysis in the innervation of the larynx. The vocal cord upon the left side was paralyzed, which accounted for the difficulty in phonation. There was also a partial paralysis of the left sterno-cleido-mastoid and trapezius muscles, which accounted for the fact that the head was held toward the left and the patient was unable to turn it toward the right.

The *splanchnic sensory component* showed no pathological disturbances.

The laboratory findings showed a spinal fluid increased in tension and quantity, containing 200 lymphocytes to the cubic mm. The Noguchi reaction was positive; the Wassermann reaction was negative. The blood and urine showed no pathological changes.

INTERPRETATION AND ANATOMICAL ANALYSIS. Upon postmortem examination, it was found that the child was suffering from a small tuberculoma in the reticular formation of the medulla oblongata on the left side.

Evidence of the focus of the lesion was furnished by the simultaneous involvement of the left vocal cord, the left sterno-cleido-mastoid and the trapezius muscles, which points to the nucleus ambiguus and the accessory portion of the spinal accessory nucleus.

Evidence of circumscription of the lesion shows that no other tracts or portions of the gray matter in the medulla oblongata were involved, since there were no somatic sensory or splanchnic sensory symptoms, and no other splanchnic symptoms than those mentioned. This draws a distinct boundary about the nucleus ambiguus and nucleus accessorius.

DIAGNOSIS AND PATHOLOGY. The lesion in this case was a tuberculoma in the medulla oblongata.

NOMENCLATURE. This syndrome is known as the *vago-accessory syndrome* or the *syndrome of Schmidt*.

SUMMARY. The essential clinical features of the syndrome of Schmidt are:

1. Ipsilateral paralysis of the larynx (laryngoplegia).
2. Ipsilateral paralysis of the sterno-cleido-mastoid and trapezius muscles, producing an inability to turn the head, so that the chin points to the side of the lesion (cephalogyric paralysis).
3. The absence of all other splanchnic motor paralysis.
4. The absence of any somatic motor or sensory disturbance.

Syndrome of the Nucleus Ambiguus, Nucleus Accessorius and Nucleus Hypoglossus. **HISTORY.** A man, forty years of age, who gave the history of having had an initial luetic lesion in his thirtieth year, gradually became aware of difficulty in swallowing and an increasing

huskiness in his voice. His intonation became nasal. He also noticed that it was difficult for him to turn his head to the right. He gave a history of a positive Wassermann reaction in the blood three years before he came under observation. Following this report he had received some irregular antiluetic treatment for six months. After a course of intensive antiluetic therapy, his symptoms entirely disappeared.

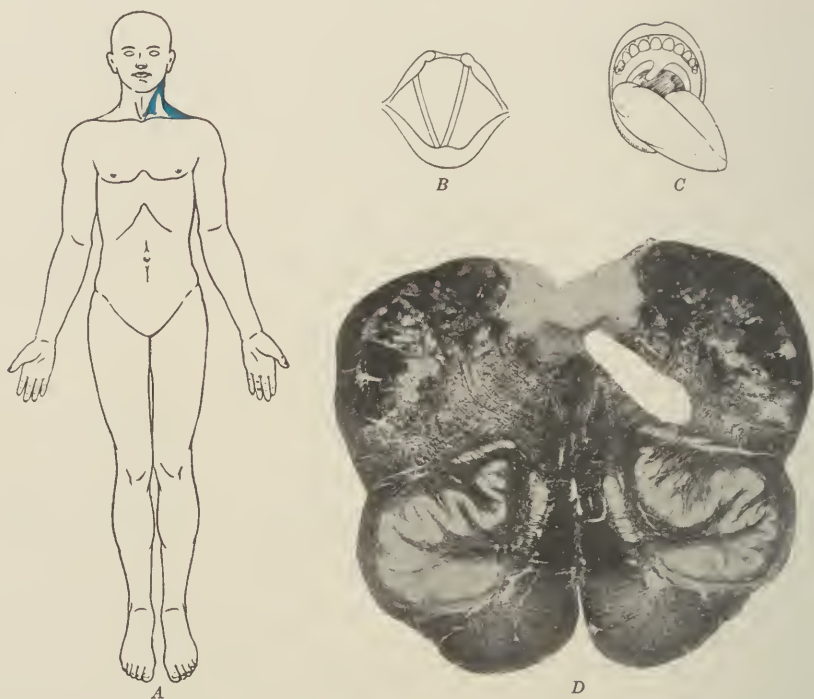


FIG. 267.—A, B and C. Syndrome of the nucleus ambiguus, nucleus accessorius and nucleus hypoglossus; syndrome of vago-accessory hypoglossal paralysis: syndrome of Jackson. Blue indicates a lower motor neurone paralysis of the left sterno-cleido-mastoid and trapezius muscles. There is also a paralysis of the left vocal cord, the left half of the tongue and the left half of the soft palate. The lesion in this syndrome occupies the same location as in the syndrome of Tapia (see page 350), but extends caudally to involve the nucleus accessorius.
D. Cross section of medulla showing involvement of nucleus hypoglossus and nucleus ambiguus.

EXAMINATION. When he first came under observation, complaining of disturbances in his nervous system, he presented the following symptoms:

With the exception of the left side of his tongue, which showed a paralysis with marked atrophy, *the somatic motor component*, that is, his idiodynamic, reflex and tonic, volitional, equilibratory, synergic and associated automatic controls was normal. The paralysis in his tongue was confined to the left side, which caused the tip of the tongue to point to the left when protruded.

The *somatic sensory component* was normal in all qualities of sensibility.

The *splanchnic motor component* showed a paralysis of the left vocal cord with a paralysis of the left half of the soft palate. The left sterno-cleido-mastoid and trapezius muscles being paralyzed, it was impossible for the patient to turn his head to the right.

The *splanchnic sensory component* showed nothing abnormal.

The Laboratory Findings. The Wassermann test of the blood and spinal fluid were both four plus positive. The spinal fluid showed twenty cells and a positive Noguchi reaction. After intensive treatment by the Swift-Ellis method, the positive reaction of the blood and spinal fluid disappeared.

INTERPRETATION AND ANATOMICAL ANALYSIS. In this case the lesion was due to neurosyphilis of the meningo-vascular type.

Evidence of the focus of the lesion is given by the simultaneous involvement of three of the cranial nerve nuclei which occupy a position in the medulla oblongata and are in close proximity to each other, namely, the nuclei of the tenth, eleventh and twelfth cranial nerves.

Evidence of circumscription of the lesion is given by the absence of involvement in other portions of the splanchnic motor or sensory components and absence of all other somatic motor or sensory disorders.

DIAGNOSIS AND PATHOLOGY. The diagnosis is neurosyphilis, affecting the medulla oblongata, and the pathology is that of vascular neurosyphilis.

NOMENCLATURE. This is known as the *syndrome of vago-accessory-hypoglossal paralysis*. It is also called the *syndrome of Jackson*.

SUMMARY. The essential clinical features in the syndrome of Jackson are:

1. Ipsilateral paralysis of the soft palate (palatoplegia).
2. Ipsilateral paralysis of the larynx (laryngoplegia).
3. Ipsilateral paralysis of the sterno-cleido-mastoid and trapezius muscles (cephalogyric paralysis).
4. Ipsilateral paralysis of the tongue accompanied by atrophy.
5. The absence of all other splanchnic motor and sensory disturbances.
6. The absence of all other somatic motor and sensory disturbances.

Syndrome of the Nucleus Ambiguus and Spinal Fillet (Spino-Thalamic Tract). **HISTORY.** A woman, sixty-six years of age, was suddenly seized with vertigo and became unconscious. She regained consciousness in half an hour and found that she had much difficulty in swallowing and talking. She could scarcely make her voice audible. She gave a previous history of prolonged high blood pressure, ranging from 200 to 230, and at the time when she came under clinical observation her blood pressure was 265. She was kept in bed for two weeks, the possibility of an extensive cerebral hemorrhage being apprehended. At the end of this time she was allowed gradually to resume some of her usual activities. She never entirely recovered, and until the time of her death, two years later, had considerable difficulty in swallowing and talking.

EXAMINATION. When examined at the onset of her symptoms she showed the following:

The *somatic motor component* was normal in all respects. There was no disturbance in the idiodynamic, reflex or tonic, volitional, equilibratory, synergic or associated automatic control of the muscles of the body. The twelfth cranial nerve was normal.

The *somatic sensory component* showed a marked disturbance. There was a complete loss of the pain-temperature sensibility on the left side of

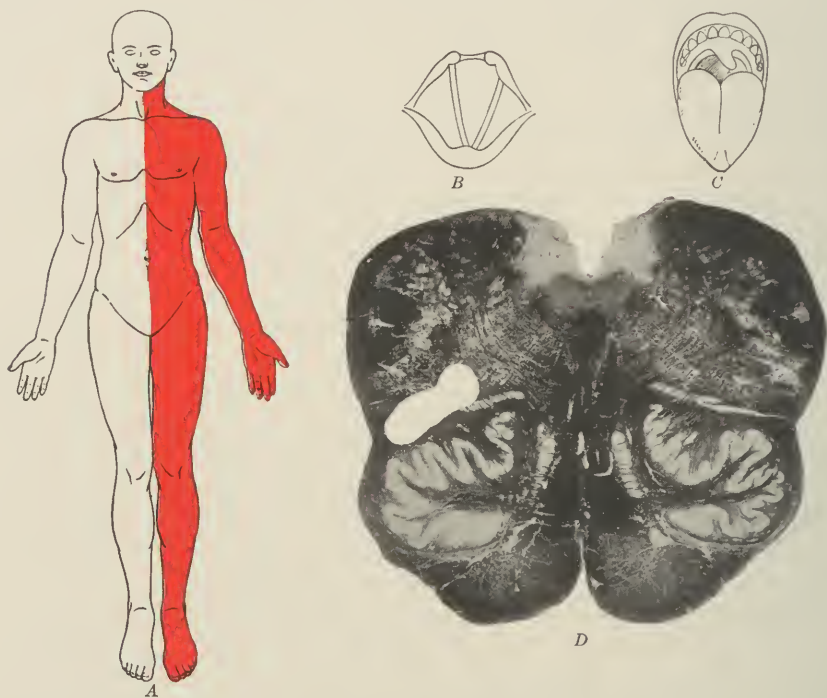


FIG. 268.—A, B, and C. Syndrome of the nucleus ambiguus and spinal fillet (spino-thalamic tract); syndrome of Avellis. Red indicates a loss of pain and temperature sensibility. There is a lower motor neurone paralysis of the right vocal cord and right half of the soft palate.

D. Cross section through the medulla showing the location of the lesion in the *syndrome of Avellis*: Involvement of the nucleus ambiguus and spino-thalamic tract (spinal fillet).

the body, although both sides of the face showed no sensory disturbance at any time; the left side of the head and neck dorsal to the interauricular line showed a loss of pain and temperature sensibility. In the areas in which the affective types of sensation were defective, there was no disturbance in vibratory sense, discriminative, tactile, muscle or joint sense. The hurt element in sensation was completely lost or decidedly diminished on the left side of the body in the areas mentioned. This was true for pinching, pressure and sharp percussion, as well as pin-point. Sensibility upon the right side of the body was normal in all qualities.

The *splanchnic motor component* showed a paralysis of the vocal cord on the right side, also a paralysis of the right half of the soft palate.

The *splanchnic sensory component* was normal.

There was no change in the mental status. Laboratory findings were negative.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion, in the light of the high blood pressure, was undoubtedly due to a hemorrhage in one of the radicular arteries supplying the medulla oblongata.

Evidence of the focus of the lesion is given by the simultaneous involvement of the nucleus ambiguus which supplies the larynx and palate, and the spino-thalamic tract (spinal fillet). In the lateral white column of the medulla, these two elements lie close together, so that a small lesion might involve both.

Evidence of circumscription of the lesion is afforded by the absence of involvement of all the other cranial nerves, and by the fact that none of the pathways, either for somatic motor or somatic sensory conduction, except the spino-thalamic tract, was affected.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is hemorrhage in the medulla oblongata with a consequent impairment of conduction in the spino-thalamic tract, and also impairment of the nucleus ambiguus which supplies the larynx and palate.

NOMENCLATURE. This is known as the *syndrome of the spinal fillet and nucleus ambiguus*. It is also called the *syndrome of Avellis*.

VARIATIONS. In some cases the lesion may extend dorsally to involve the pupillary center of the medulla, which consists of a group of cells situated dorsal to the nucleus ambiguus. When such is the case the syndrome of Avellis is complicated by the *syndrome of Horner*. This syndrome consists of ipsilateral enophthalmos (sinking in of the eye-ball), myosis, (narrowing of the pupils), and sympathetic ptosis, *i.e.*, slight drooping of the upper lid.

SUMMARY. The essential clinical features of the syndrome of Avellis are:

1. Ipsilateral paralysis of the vocal cord and soft palate (laryngoplegia and palatoplegia).
2. Contralateral loss of pain and temperature sensibility in the leg, trunk, arm, neck and skin over the scalp up to the interauricular line. This loss of pain and temperature sensibility is hemisomatic.
3. The retention of all other types of somatic sensation in the areas showing defects in pain and temperature sensibility.
4. The absence of any other sensory or motor disturbance in the body.

Syndrome of the Nucleus Ambiguus and Nucleus Hypoglossus.

HISTORY. A child six years of age, after suffering for three weeks from a prolonged sleep as the result of epidemic encephalitis (the so-called sleeping sickness), presented upon examination paralysis and atrophy of the left side of the tongue with paralysis of the left vocal cord and left half of the soft palate. At the end of several months these conditions gradually im-

proved and the child finally made a complete recovery. The laboratory findings upon the blood, urine and spinal fluid were negative.

EXAMINATION. Upon examination after recovering from the prolonged period of somnolence, the following symptoms were observed:

The *somatic motor component* showed that all the muscular structures of the body, with the exception of the left side of the tongue, were normal in their idiodynamic, tonic, reflex, volitional, equilibratory, synergic and automatic associated controls. The tongue showed a distinct paralysis of the left side when protruded and presented a marked atrophy.

The *somatic sensory component* was normal.

The *splanchnic motor component* showed a paralysis of the left vocal cord and the left half of the soft palate.

The *splanchnic sensory component* was normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion in this case was the result of the encephalitis from which the child had originally suffered.

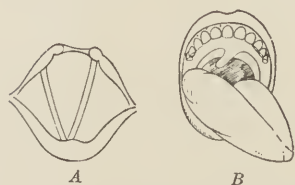


FIG. 269.—Syndrome of the nucleus ambiguus and the nucleus hypoglossus (syndrome of Tapia).

A—Lower motor neurone paralysis of the left vocal cord. B—Lower motor neurone paralysis of the soft palate and left half of the tongue.

Evidence of the focus of the lesion points to a position in the medulla in which the hypoglossal and vagus nerves have been simultaneously affected.

Evidence of circumscription of the lesion is afforded by the absence of all other sensory and motor symptoms, in either the splanchnic or motor components.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is poliomyelitis, involving the medulla oblongata. The pathological process was an inflammatory reaction in this region of the brain.

NOMENCLATURE. This is the *syndrome of the nucleus ambiguus and nucleus hypoglossus*: it is also called the *syndrome of Tapia*.

VARIATIONS. The same combination of symptoms sometimes occurs from involvement due to injury to the peripheral nerves. It is usually the result of gunshot injuries affecting the hypoglossal and vagus nerves in their cervical course.

SUMMARY. The essential clinical features of the Syndrome of Tapia are:

1. Ipsilateral paralysis of the vocal cord and soft palate (laryngoplegia and palatoplegia).
2. Ipsilateral paralysis with atrophy of the tongue (atrophic glossoplegia).
3. Absence of all other motor and sensory symptoms.

Syndrome of the Circumferential and Intermediate Zones. **HISTORY.** A man, sixty-five years old, on rising in the morning, had difficulty in talking. When he attempted to swallow, the fluid regurgitated through the nose and caused him to cough. He at once consulted a laryngologist, who found that the right vocal cord and right half of the soft palate were paralyzed. During this examination the patient experienced a feeling

of extreme vertigo and when he attempted to walk, he noticed that he staggered to the right. He was taken home still suffering from dizziness. After several hours both eyes were noticed to be drawn over into conjugate deviation to the right side. He remained in this critical condition for a number of weeks, during which time it was necessary to feed him by tube because of his marked dysphagia. Subsequently he improved and finally made a complete recovery.

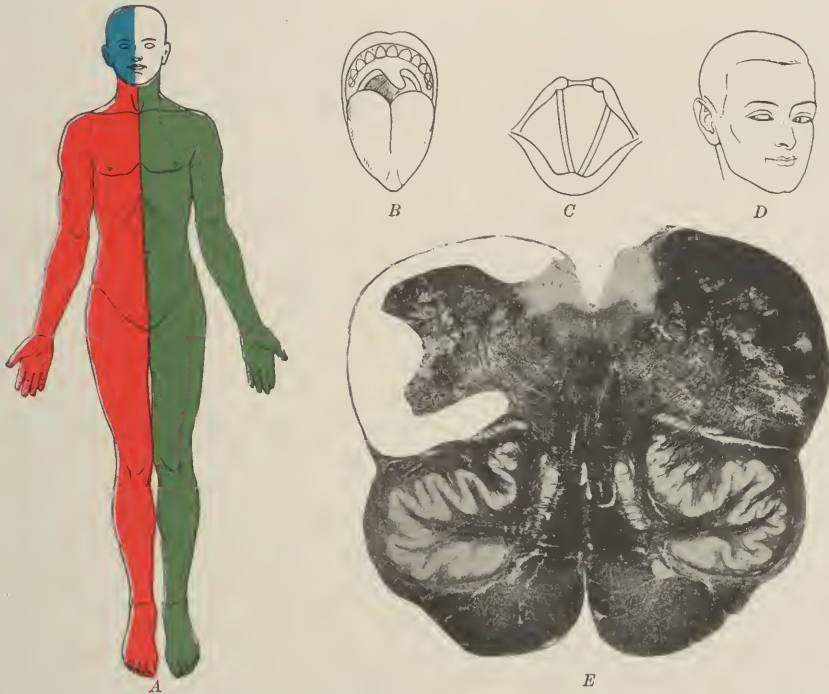


FIG. 270.—A, B, C and D. Syndrome of the circumferential and intermediate zones; syndrome of the posterior inferior cerebellar artery. Red indicates a hemiasynergia, swaying and lateropulsion to the right. Blue indicates a loss of all types of sensibility. Green indicates a loss of or decrease in pain and temperature sensibility. There is a lower motor neurone paralysis of the right half of the soft palate and the right vocal cord with a right conjugate deviation of the eyes.

E. Cross section through the medulla showing the location of the lesion in the *syndrome of the posterior inferior cerebellar artery*: Involvement of the spino-cerebellar, spino-thalamic and descending trigeminal tracts, together with the nucleus ambiguus and vestibular nuclei.

EXAMINATION. Examination at the time of the onset of his symptoms, showed the following:

The *somatic motor component* showed that idiodynamic, reflex and tonic, volitional, and automatic associated controls were normal in all parts of the body. He suffered, however, from a marked hemiasynergia of the right side. All movements of the upper and lower extremity on the right side were made with great uncertainty and showed a distinct lack of cooperation in the synergic units of the right arm and leg. In attempting to walk, he

swayed to the right and even staggered in this direction, giving rise to a symptom known as lateropulsion. Equilibratory control was distinctly affected. When he attempted to stand, with his eyes either open or closed, there was a tendency to fall to the right or else to move his feet so as to establish a broader basis upon which to support his body. Both eyes were drawn over to the right side in an extreme lateral position. His hypoglossal nerve was normal.

The *somatic sensory component* showed a loss of all types of sensibility on the right side of the face and head, up to the interauricular line and reaching the sagittal line in front. This loss of sensation was also observed in the cavities of the nose and mouth upon the right side. In addition to this loss of sensation upon the right side of the face, the left side of the body, including the neck and the skin over the scalp up to the interauricular line, presented a decrease in the pain-temperature sensibility. The senses of smell and vision, as well as the sense of hearing, were normal. The slightest movement of the head increased his vertigo to an extreme degree, so that it was necessary for him to lie as nearly motionless as possible.

The *splanchnic motor component* showed a paralysis of the right vocal cord and the right half of the soft palate.

The *splanchnic sensory component* was normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion was evidently due to a vascular accident, in view of its sudden occurrence and its tendency toward improvement.

Evidence of the focus of the lesion indicates a region in the medulla oblongata in which fibers concerned in equilibratory and synergic control, as well as the pathway for pain and temperature sensibility, are simultaneously involved. The symptoms referable to the nucleus ambiguus indicate a position in the lateral white column. It is possible to locate in this position all of the tracts necessary to explain the symptoms. The disturbances of equilibratory and synergic control indicated by the hemiasynergia, the ataxia and the lateropulsion, were attributed to the dorsal and ventral spino-cerebellar tracts. Immediately mesial to the dorsal spino-cerebellar tract at this level is situated the descending trigeminal tract, conveying afferent impulses from the same side of the face. This would explain the ipsilateral hemianesthesia of the face. The vertigo and dextroversion (turning to the right of both eyes in conjugate position) are explained by irritation to the vestibular nuclei situated in close relation to the descending trigeminal tract. The loss of pain-temperature sensibility on the opposite side of the body may be attributed to involvement of the spino-thalamic tract (spinal fillet) which conveys sensory impulses from the contralateral side of the body. The ipsilateral paralysis of the vocal cord and of the soft palate denotes an involvement of the nucleus ambiguus on the same side.

Evidence of the focus of the lesion places the pathological process in the circumferential and intermediate zones on the right side of the medulla oblongata.

Evidence of circumscription of the lesion is furnished by the absence of

all other somatic sensory or motor, as well as splanchnic motor or sensory symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is a vascular disease involving the lateral portion of the medulla oblongata and due in all probability to thrombosis.

NOMENCLATURE. This is the *syndrome of the circumferential and intermediate zones of the medulla oblongata* or the *syndrome of the posterior-inferior cerebellar artery*.

SUMMARY. The essential clinical features of the syndrome of the posterior-inferior cerebellar artery are:

1. Ipsilateral lateropulsion, hemiasynergia and hemiataxia.
2. Ipsilateral hemifacial anesthesia, including all types of sensibility.
3. Contralateral loss of pain-temperature sensibility in the arm, trunk, leg, neck and skin over the scalp up to the interauricular line.
4. Ipsilateral laryngoplegia and palatoplegia.
5. The absence of all other somatic motor and sensory and splanchnic motor and sensory symptoms.

The Syndrome of the Vestibular Nuclei. **HISTORY.** A man who gave the history of no disturbances in the sense of hearing or in the other special senses, on attempting to rise one morning, was suddenly seized with extreme vertigo which caused him to fall. He attempted to rise to his feet again, but each effort resulted in so complete a loss of equilibrium that he fell to the floor. He eventually managed to creep back to his bed with great difficulty, but the extreme vertigo continued even while lying down. It seemed to him that the bed was swinging around on its long axis. Every attempt to lift his head increased the dizziness. He experienced a feeling similar to sea-sickness and soon began to vomit. This persisted for the remainder of the day and yielded to no treatment. The vertigo continued for three days and then gradually abated. During this time he remained in bed. In the course of a week he was able to be up and about again. He resumed business in ten days and was apparently in good health for six months when he had another attack similar in all respects to the one just described. At irregular intervals for the next ten years he experienced recurrences of these symptoms. Except for these attacks he enjoyed good health and was not disturbed by any distressing symptoms.

EXAMINATION. Upon examination at the time of the onset of his acute symptoms, he showed the following:

The *somatic motor component* revealed no disturbance in the idiodynamic, reflex or tonic, volitional, synergic or automatic associated controls. His equilibratory control was completely overthrown, and he was not only unable to maintain an upright position in standing, sitting or walking, but when recumbent had an extreme sense of vertigo, as if his body were in constant motion about the long axis. In the early part of his extreme paroxysmal vertigo there was a nystagmus of the eyes, that is, oscillatory movement from side to side. This was irregular at times, but at other times could be resolved into a fast and slow component of the labyrinthine type.

The *somatic sensory component* was normal. Special sensory examination showed that the sense of smell, the sense of vision and the sense of hearing were without defect. A careful investigation of the auditory nerve failed to reveal any evidence of involvement of the middle or internal ear.

The *splanchnic motor* and *splanchnic sensory components* were normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. From the acute paroxysmal character of the attacks, and the intervals of long duration when the patient was free from all of his symptoms, it is evident that the nature of the lesion must have been that of an angiospasm not unlike the pathological conditions which produce the "twenty-four hour hemiplegia."

Evidence of the focus of the lesion is furnished by the fact that the main symptoms were the overthrow of equilibratory control, accompanied by an extreme sense of vertigo and some nystagmus. If this were to be placed centrally, the most likely position would be in connection with the vestibular nuclei in the medulla oblongata. This focus is selected from the fact that the vestibular area of the medulla is abundantly supplied with a leash of vascular channels which make it stand out in contrast to other adjacent portions of the medulla. The high vascularity of this region of the medulla oblongata has been noted by Hoyt in recent studies on the primate brain.

Evidence of circumscription of the lesion is furnished by the fact that the aural examination exempted the middle and internal ear from all responsibility in connection with the symptoms. It should be borne in mind, however, that both the middle and internal ear may be incriminated by symptoms of the character recorded in this case. It is the clinical rule that when there is no sign of involvement of the cochlear division of the eighth nerve, the evidence is against an affection disturbing either the middle or the internal ear. Furthermore, the acute, paroxysmal nature of the disease would indicate some transitory lesion, inasmuch as the intervals between attacks were quite free from symptoms. The evidence of circumscription of the lesion is also furnished by the absence of any motor symptoms other than those due to the overthrow of equilibratory control, and also to the lack of sensory symptoms; these facts draw a line about the focus of the lesion limiting it to the region of the vestibular nuclei.

DIAGNOSIS AND PATHOLOGY. The diagnosis is an involvement of the medulla in the region of the vestibular nuclei due to an angiospasm.

NOMENCLATURE. This is the *syndrome of the vestibular nuclei*, and is sometimes referred to as the *syndrome of Ménière*.

It is to be noted that this syndrome is usually the result of involvement of the internal ear. Ménière's disease is in fact, an acute hemorrhagic condition involving the vestibular and cochlear structures of the internal ear.

VARIATIONS. In Ménière's disease the symptoms are similar to those of the case already recorded, with the exception, however, that the sense of hearing is implicated.

SUMMARY. The essential clinical features of Ménière's syndrome due to the involvement of the vestibular nuclei are:

1. Paroxysmal attacks of vertigo with intervals either completely free from all symptoms, or during which the symptoms are negligible.

2. The loss of equilibratory control.
3. The normal state of the sense of hearing.
4. The absence of any other somatic motor or sensory disturbance or of any splanchnic motor or sensory disorders.

Syndromes Due to Multiple Lesions in the Medulla Oblongata. Several other syndromes of the medulla have been described. They occur with sufficient frequency to make them of anatomical interest. These disorders are due to diffuse, multiple lesions affecting different parts of the gray and white matter. Two of them in particular may be mentioned:

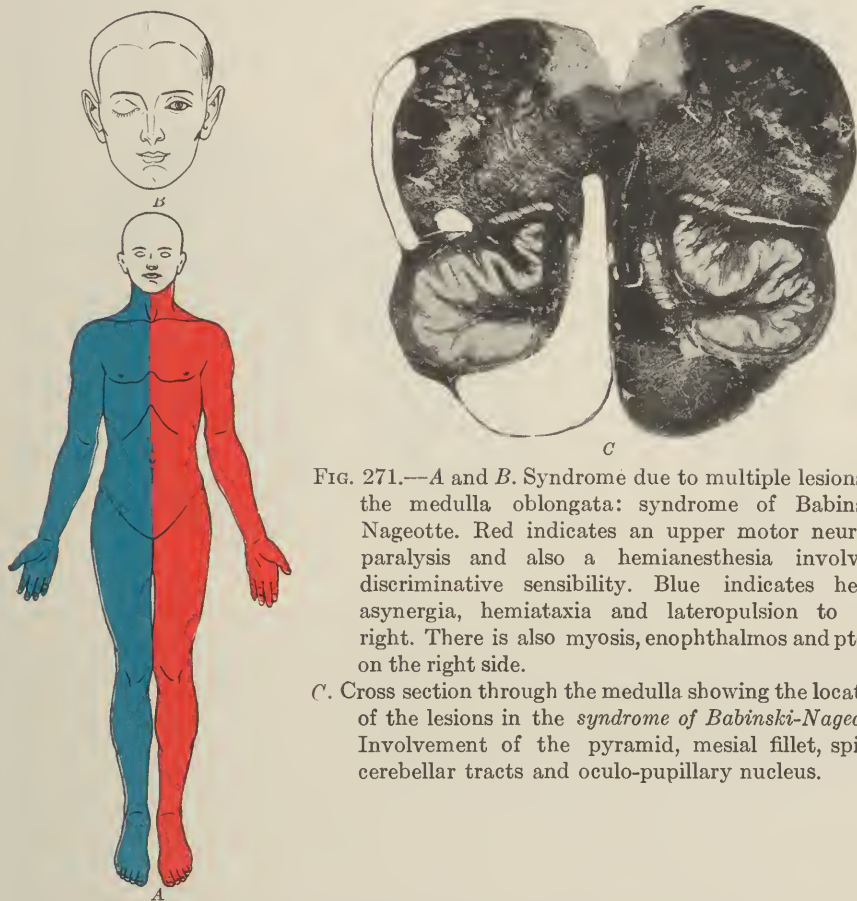


FIG. 271.—A and B. Syndrome due to multiple lesions in the medulla oblongata: syndrome of Babinski-Nageotte. Red indicates an upper motor neurone paralysis and also a hemianesthesia involving discriminative sensibility. Blue indicates hemiasynergia, hemiataxia and lateropulsion to the right. There is also myosis, enophthalmos and ptosis on the right side.

C. Cross section through the medulla showing the location of the lesions in the *syndrome of Babinski-Nageotte*: Involvement of the pyramid, mesial fillet, spinocerebellar tracts and oculo-pupillary nucleus.

A. The Syndrome of Babinski-Nageotte. This syndrome results from the multiple lesions which affect the pyramid and fillet, the inferior cerebellar peduncle and the reticular formation. Its symptoms are:

1. Contralateral hemiplegia.
2. Contralateral hemianesthesia involving discriminative sensibility in the arm, leg and trunk, neck and scalp up to the interauricular line on the side opposite the lesion, with retention of pain and temperature sensibility. The face is usually unaffected.

3. Ipsilateral lateropulsion, hemiasynergia and hemiataxia, due to the fact that the inferior cerebellar peduncle bearing afferent impulses from the muscles to the cerebellum has been involved.

4. Myosis, enophthalmos and ptosis (Horner's Syndrome), due to the involvement of the oculopupillary center in the medulla oblongata.

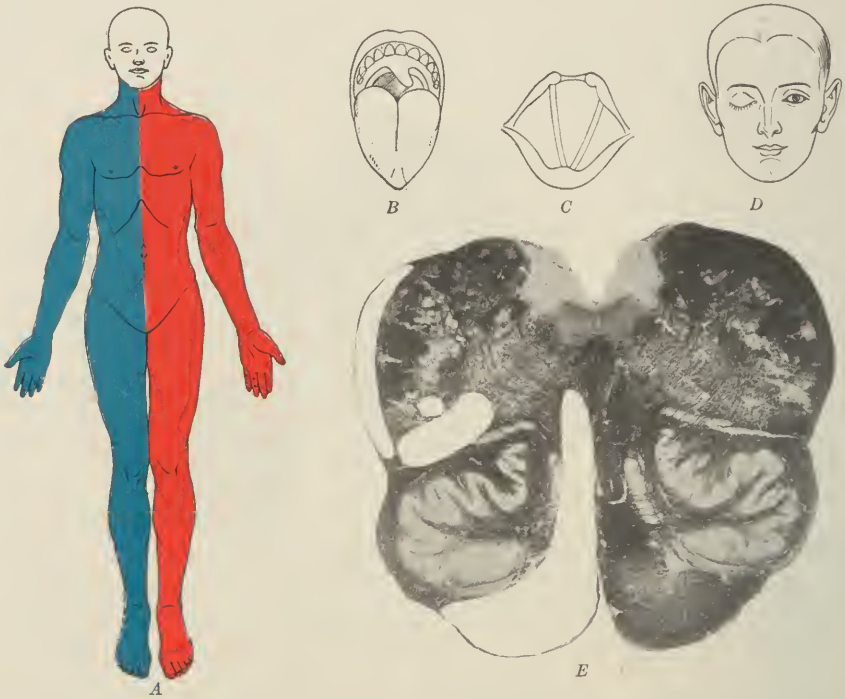


FIG. 272.—A, B, C and D. Syndrome of multiple lesions in the medulla oblongata: syndrome of Cestan-Chenais. Red indicates an upper motor neurone paralysis and a hemianesthesia affecting all types of sensibility. Blue indicates a hemiasynergia, hemiataxia and lateropulsion to the right. There is a lower motor neurone paralysis of the right half of the soft palate and left vocal cord. There is also myosis, enophthalmos and ptosis on the right side.

E. Cross section through the medulla showing the location of the multiple lesions in the syndrome of Cestan-Chenais: Involvement of the pyramid, mesial fillet, spinothalamic and spino-cerebellar tracts with the nucleus ambiguus and nucleus oculo-pupillaris.

All of these symptoms could not be explained on the basis of a single lesion, and pathologically it has been shown that the involvement is usually due to scattered foci in the distribution of the vertebral artery.

B. The Syndrome of Cestan-Chenais. This syndrome is due to scattered lesions involving the pyramid, the fillet, the inferior cerebellar peduncle, the nucleus ambiguus, the oculo-pupillary center and sometimes the spinothalamic tract.

The symptoms in consequence of this involvement are:

1. Contralateral hemiplegia.

2. Contralateral hemianesthesia, involving discriminative sensibility of the opposite leg, trunk, arm, neck and scalp, up to the interauricular line.

3. Contralateral loss of pain and temperature sensibility of the leg, trunk, arm, neck and scalp, up to the interauricular line. The sensibility in the face remains normal in this syndrome.

4. Ipsilateral hemiasynergia with lateropulsion.

5. Myosis, enophthalmos and ptosis (Horner's syndrome).

6. Ipsilateral paralysis of the soft palate (palatoplegia).

7. Ipsilateral paralysis of the larynx.

The symptoms are due to the scattered areas of degeneration in consequence of thrombosis of the vertebral artery, or arise as part of a syndrome due to multiple sclerosis.

CHAPTER XX

THE PONS VAROLII

SIGNIFICANCE, ANATOMY AND EMBRYOLOGY OF THE PONS

The Pons, a Structure of the Mammalian Brain. In the human brain, the portion of the neuraxis immediately cephalad of the medulla oblongata is the pons Varolii. It occupies a position in the mesial portion of the posterior cranial fossa. As an anatomical division of the brain, it takes its importance from the fact that it appears in mammals only and reaches its highest development in man and the anthropoid apes. It is not found in fishes, amphibia, reptiles or birds. The term pons, therefore, has a limited application in the description of the brain of vertebrates. What accounts for its prominence in anatomy? The answer to this question sheds much light upon many advances in the development of the brain and also reveals the pons Varolii in a dynamic rôle during the process of evolution.

In the lower vertebrates, the tegmentum of the myelencephalon is continuous with that of the metencephalon without appreciable line of demarcation. In mammals the pons is swung like a suspension bridge across the ventral surface of the tegmentum of the hind-brain, being suspended upon either side from the cerebellum by means of the middle cerebellar peduncle. It forms one of the three major divisions of the metencephalon which, in order of their derivation from the neural tube, are:

1. The tegmentum, the primitive segmented portion of this division of the brain common to all vertebrates.
2. The cerebellum, an early derivative of the neural tube which is variable in its development through the vertebrate series.
3. The pons Varolii, a recently acquired structure which is present in mammals only.

The usual anatomical descriptions of this region recognize two divisions in the hind-brain, the cerebellum and the pons. This, however, does not give full value to the primitive portion of the metencephalon, the tegmentum, which is the direct cephalic continuation of the neuraxis. Usage has conventionalized the term "pons" in the description of the hind-brain; but it should be borne in mind that this nomenclature is one of convenience, based on the conditions found in mammals. In the mammalian brain, the so-called pons consists of:

1. The pontile basis of the metencephalon, or *pars basilaris pontis*.
2. The tegmentum of the metencephalon, the primitive segmented portion, or *pars dorsalis pontis*.

Significance of the Pons. It is evident from these facts that the pons must have a significance peculiar to the development of mammals. Even

among the mammals themselves this structure varies in size and prominence. In the lower forms the pons is small and does not entirely cover the ventral surface of the hind-brain. In the anthropoid apes and man it is the most prominent element on the ventral surface.

The principal constituents of the pons are nerve fibers, which participate in establishing a connection between the cerebral cortex and the cerebellum. In man this is a massive connection far exceeding in size that between the motor cortex of the cerebrum and the spinal cord. There appears to be a need of this connection in the mammalian brain which does not exist in lower vertebrates, while the demands made upon it are greatest in the most highly developed mammals.

The fibers to the pons arise in the frontal, parietal, temporal and occipital regions of one side of the cerebral cortex and by relay communicate with the lateral lobe of the cerebellum of the opposite side. This connection brings the cerebellum under the influence of those regions of the cerebral cortex which are related to volitional control of the muscles, to somatic sensibility and also to auditory and visual sensibility. A clew to the nature of this pallio-cerebellar connection is given in the functions attributed to the cerebellum. This part of the brain is now regarded as the important organ for synergic control. The regulation of motion mediated through the cerebellum thus comes under the influence of the auditory, the visual, the somatic sensory and motor activities of the cerebral cortex. Man has the greatest need of such influences; the lower mammals require much less. Among mammals, although synergic regulation is necessary, there are salient differences in the control of motion.

The motor activities in the lower animal are to a great extent limited to performances which are common to its kind. A quadruped has a range of action peculiar to its species, and the animal is able to go but little beyond this limit, however much it may be trained. In large measure its motor activities are phylogenetically conditioned—that is, they are part of the heritage of its species. Although much of the motor activity in man is similarly conditioned, there has been created an extensive superstructure of volitional control, in consequence of which the individual is capable of expanding his motor accomplishments to a remarkable degree.

By far the greater part of human motor activity for this reason is ontogenetically conditioned, that is, dependent upon what the individual makes of it. Such is the case with speech and handwriting. The training of the voice in singing, dexterity in the use of certain instruments and implements, proficiency in the skilled manipulation of the arts and sciences, are all individual acquirements.

Skilled acts of the kind mentioned have greater need of synergic control than more simple motor performances, and on this account the synergic organ of the brain has acquired close communication with the visual, auditory, and somatic sensory and motor areas of the cerebral cortex in the special interest of adequate supervision of these motions. Skilled movements vary in direct ratio with intelligence. The higher the intelligence, the richer

the pallio-cerebellar connection which determines the synergic control. The *modus operandi* of this pallio-cerebellar connection is best conceived by picturing the course of a motion formula for a skilled act, such as handwriting. This formula arises in the cerebral cortex and leaves the brain by way of the pallio-spinal pathway to reach the muscles. Simultaneous with the despatch of this formula, impulses leave the frontal, visual, sensory and auditory areas of the brain destined for the cerebellum. These impulses have the purpose of bringing the synergic mechanism into play and of regulating the muscles participating in the skilled act.



FIG. 273.—Diagrammatic representation of the metencephalon (pons) in the vertebrate series, ventral view. Darkened area.

Lepus (rabbit) above. *Canis familiaris* (dog) below.¹

The Pons an Index of Cortical Development. In this light, the pons Varolii stands as an index of the degree of development in the cerebral cortex. In the metencephalon, the decussation which serves the function of hearing takes place in the most ventral portion of the tegmentum. In the lower mammals the crossing fibers of this decussation form a recognizable mass called the *trapezoid body*. As the cerebral cortex becomes more extensively developed, the pons attains such size that it overlaps and finally conceals this body. The mammal in which the corpus trapezoideum remains uncovered by pontile fibers has a low degree of development in its cerebral cortex. Complete concealment by the pons is indicative of an animal having a cerebral cortex with a considerable degree of expansion.

Significance of the Metencephalic Tegmentum. The metencephalic tegmentum differs little in its significance from that of the medulla oblongata. In both myelencephalon and metencephalon the tegmental portion serves in the same general capacity. The autonomy which the medulla holds over the vital processes finds an ancillary region in the tegmentum of the metencephalon. Although the functional responsibilities of the hind-brain may be less vital to the organism, nevertheless they are essential complements to the activities carried on by the gray matter of the medulla oblongata. This is especially true of the motor control exerted by the metencephalon over the jaw muscles which provide important actions in the ingestion of food, in its preliminary preparation by mastication and its subsequent deglutition. In addition, the development of the facial nucleus contributes an auxiliary motor control necessary in several ways to the vital processes. The tegmentum of the metencephalon also contains an important center for the regulation of eye movements, the nucleus of the sixth cranial nerve.

In summary, the pons Varolii is significant in its basal portion as an index of the degree of skilled movement of which the animal is capable. In its tegmental portion it is complementary to the medulla oblongata in the regulation of the vital processes, and participates in the important control over movements of the eyes.

Features in the Embryological Development of the Pons. In the early stages of development, the neural plate gives evidence of a more rapid progress of growth in the encephalon than in the myelon. The neural folds rise in this region more rapidly, and gradually approach each other in the mid-dorsal plane. Their first line of contact and fusion occurs in the fore-brain and subsequently in the region of the midbrain. The neural folds, however, do not come into close relation in the region of the brain immediately caudal to the mesencephalon. Although a roof-plate is formed here, it remains an attenuated, membranous structure which subsequently stretches over the rhomboid space bounded by the lateral walls of the myelencephalon and metencephalon. It is difficult to draw a line of demarcation between these two subdivisions of the brain during the early stages of development. The fact that together they form the boundaries of the rhomboid space in the ventricular cavity has led to the use of the term *rhombencephalon* in the description of these two divisions of the encephalon. At the caudal extremity of the rhombencephalon the neural folds have approximated each other and formed a firm fusion across the midline. Cephalad to this line of fusion the central canal forms a large cavity which is the fourth ventricle. In the early stages it has a thick floor-plate, high lateral walls and an attenuated roof-plate. The lateral walls soon begin to separate, especially in the region marking the transition from myelencephalon to metencephalon,—a process which results in a stretching out of the thin roof-plate. During this change the roof-plate not only becomes more attenuated but also in its myelencephalic portion acquires a connection with the vascular membrane, the pia mater. It thus forms the *tela chorioidea*

inferior. The roof-plate covering the metencephalic portion of the fourth ventricle does not enter into the formation of this chorioid plexus, but takes part in the development of the *superior medullary velum*. At an early stage several flexures appear in the region of the rhombencephalon, the first of which, the *cervical flexure*, develops at the junction of the myelencephalon and spinal cord. A second flexure produces a marked ventral convexity in the metencephalon. This is the *pontile flexure*. At this period of development the general outline of the floor of the fourth ventricle is that of a letter U. As the floor-plate of the ventricle begins to thicken this undulation becomes more reduced until the entire floor of the fourth ventricle lies upon the same plane. This change in the floor of the ventricle is due to numerous alterations in the internal structure of the neuraxis. Among these changes are the ingrowth of the neuraxones, constituting the several tracts which pass through the medulla oblongata and hindbrain, the decussations which take place at this level and the appearance of new masses of gray matter, such as the inferior olive. Even more effective in determining the change in the plane of the floor of the fourth ventricle is a gradual invasion by the axones which arise in the cerebral cortex, descend in the cerebral peduncle and finally reach the level of the pontile flexure. Here they are relayed by cells whose axones extend transversely and contribute to the formation of the pons Varolii. At first these fibers adhere closely to the ventral surface of the axis, some of them even passing through the ventral white column in such a way as to interpose themselves between the tegmentum and the descending pyramidal fibers. This layer of crossing pontile fibers constitutes the *stratum profundum pontis*. It has the effect of displacing the pyramidal tract fibers from their usual area in the tegmentum into a more ventral position. Many bundles of these pontile fibers interpose themselves between the fibers of the pyramidal tract, so that this tract now appears separated into many small fasciculi. The transverse fibers of the pons which cause this separation of the pyramidal tract into individual fasciculi is the *stratum complexum pontis*. Another large group of transverse crossing ponto-cerebellar fibers takes up a position superficial to the pyramidal fibers and in a more compact mass constitutes the *stratum superficiale pontis*.

Early in the development of these pontile fibers, a large number of cells migrate from the mantle layer of the neural tube. Their collected mass constitutes the pontile nuclei which are scattered among the stratum complexum and to a lesser degree in the stratum profundum and stratum superficiale pontis. The purpose of these cells is to afford a nucleus which serves to relay the pallio-pontile tracts, the fibers of which end by synapsis about the cells of the pontile nuclei. The axones of the pontile nuclei pass transversely across the midline and enter the middle cerebellar peduncle which consummates the connection between the cerebral cortex and the hemispheres of the cerebellum. The pons Varolii thus results from the invasion of the metencephalic region by a large number of neuraxones arising in the cerebral cortex. These axones, descending to this level, receive a relay and, by the pontile decussation, make a connection with the opposite lateral

lobe of the cerebellum. The addition of the pontile nuclei to the pontile fibers completes the elements essential to the formation of the pons. The entire process is in the interest of establishing a connection between the cerebral cortex and the opposite side of the cerebellum. From the manner in which this pontile formation is accomplished it is evident that the size of the pons varies directly with the volume of the pallio-cerebellar connection.

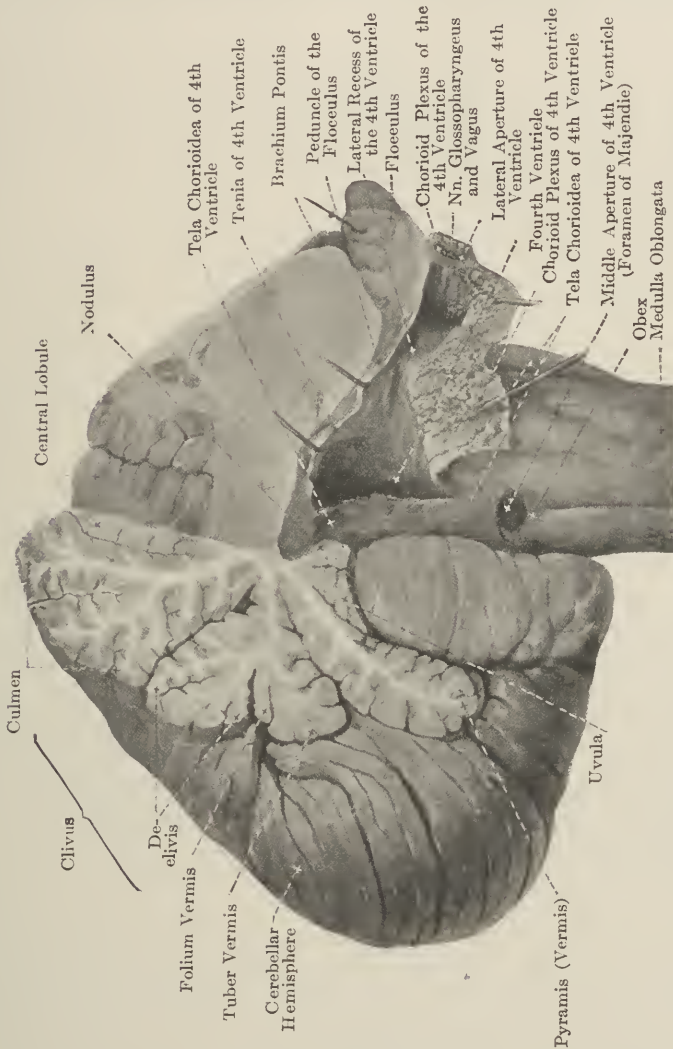


FIG. 274.—Fourth ventricle, partly opened, viewed from behind and from the right. The right half of the cerebellum has been in large part removed; the tela chorioidea of the fourth ventricle has been cut through on the right side and reflected. (*Spalteholz*.)

Situation, Boundaries and Relations of the Pons Varolii. The pons Varolii rests upon the basi-occipital portion of the occipital bone and upon the dorsum sellæ. Its lower boundary is the bulbo-pontile sulcus which, in the midsagittal line, is met by the ventro-median sulcus of the medulla. The junction of these two sulci is continued for a considerable distance under the stratum superficiale pontis, giving rise to a blind pit, the *foramen*

cecum posterius. The bulbo-pontile sulcus is also known as the *post-pontile sulcus*. The upper border of the pons is determined by the *pedunculo-pontile sulcus*, which crosses the cerebral peduncles at the cephalic margin of the pons. This is known also as the *pre-pontile sulcus*. It is met in the sagittal line by the cephalic continuation of the ventro-median sulcus, and the point of union of these two sulci is continued under the free edge of the stratum superficiale pontis for some distance, forming a blind pocket, the *foramen cecum anterius*.

Ventral to the pons is the dura mater covering the mesial portion of the posterior fossa of the skull, the vertebral artery and the two abducens nerves. Laterally, it is in relation with the two middle cerebellar peduncles and also with the lateral lobes of the cerebellum. Dorsally, it is in relation with the vermis of the cerebellum.

Dimensions and Coverings of the Pons Varolii. The pons Varolii is 25 mm. in its long axis and 30 to 35 mm. in its transverse axis. Its dorso-ventral diameter varies from 9 to 11 mm. It is covered by the pia mater which adheres closely to its surface and penetrates between the numerous transverse ridges upon the ventral surface of the pons. The arachnoid, ventral to the pons, forms a special compartment, the *cisterna pontis*. This is continuous behind with the *cisterna magna*, and in front with the *cisterna basalis*.

Arteries of the Pons Varolii. The pons receives its vascular supply from the median branches of the basilar artery, which send small branches to the nuclei of the fifth, sixth and seventh nerves. In its cephalic portion it receives branches from the superior cerebellar artery and anterior inferior cerebellar artery.

External Markings and Surface Features of the Pons Varolii. The transition from the medulla to the pons Varolii is identified by the appearance of the caudalmost pontile fibers which define the bulbo-pontile sulcus. Upon the ventral surface, the pons forms a quadrilateral figure bounded cephalad by the pedunculo-pontile sulcus and caudad by the bulbo-pontile sulcus. Laterally, the boundaries are not clear, for the ventral surface turns dorsad to form the middle cerebellar peduncle. The ventral surface is characterized by a median furrow, the *basilar groove*, lodging the basilar artery, and by a series of shallow, incomplete sulci running at right angles to the basilar groove. The lateral surface of the pons is concealed from view by the overlapping lateral lobe of the cerebellum; when this is retracted, the lateral surface has the appearance of a truncated cone, its apex directed toward the great transverse fissure of the cerebellum. The change in the size and shape of the pons at this point is due to the fact that the pontile fibers are drawing together into a dense mass, and also because there are now no cells of the pontile nuclei present. The structure upon the lateral surface is the middle cerebellar peduncle, the final link in the connection between the cerebral cortex and the lateral lobe of the cerebellum. Near the cephalic extremity of the lateral surface are the entrant and emergent fibers which make up the roots of the trigeminal nerve.

The dorsal surface of the metencephalon is concealed by the cerebellar vermis. Removal of the cerebellum discloses the floor of the fourth ventricle which consists of a cephalic triangle in relation with the metencephalon, and a caudal triangle in relation with the myelencephalon. The apex of the cephalic triangle is directed cephalad, and the apex of the caudal triangle is directed caudad. The two triangles meet at their bases and together form

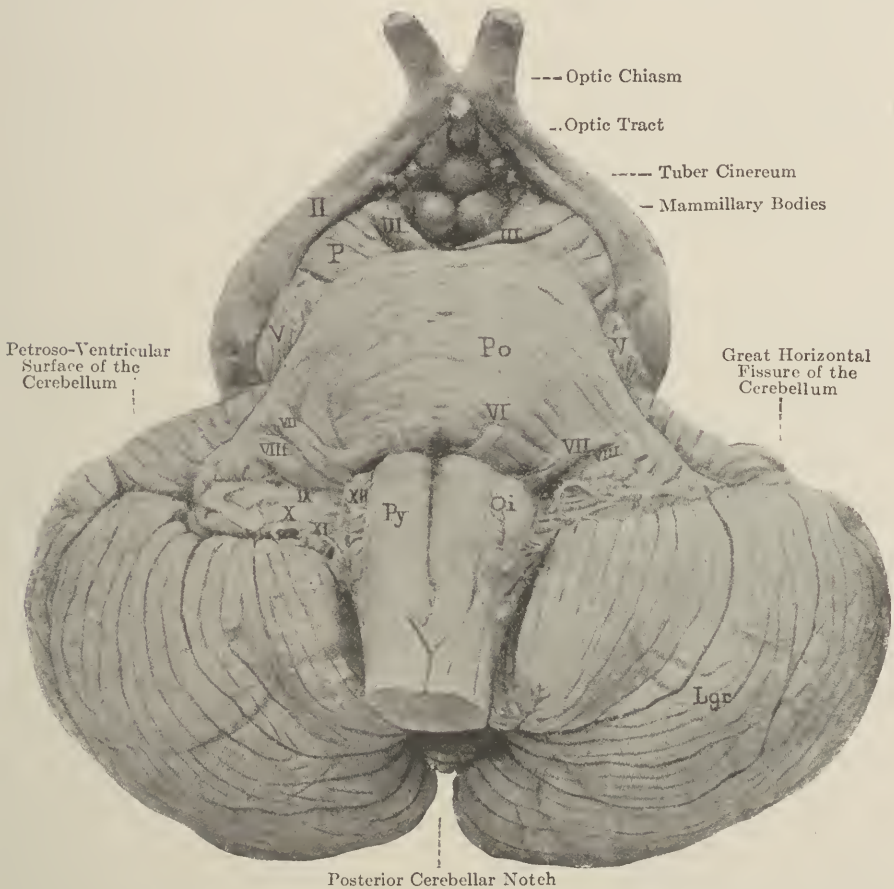


FIG. 275.—The optico-peduncular space, pons, cerebellum, medulla viewed from the front after removal of the pia mater. (*Déjerine.*)

The Roman numerals indicate the cranial nerves by number.

P—Cerebral peduncle. Po—Pons Varolii. Oi—Olivary eminence. Lgr—Cerebellum.

the rhomboid space, from which this part of the brain is known as the *rhombencephalon*.

The Floor of the Fourth Ventricle. Boundaries. The boundaries of the lower triangle of the fourth ventricle are the clavæ and the cunei. Both of these structures in their more caudal portions form high elevations on either side of the triangle; but as these eminences approach their cephalic extremities they become reduced in prominence until they finally reach

the level of the floor of the ventricle. The lateral recesses extend outward at this point.

The boundaries of the cephalic triangle are much higher, and consist of the middle cerebellar peduncle and the superior cerebellar peduncle, which latter forms the most extensive portion of the lateral boundary. The roof of the caudal triangle is formed by the *tela chorioidea inferior*, and the *inferior medullary velum*, which is attached to a thin line of gray matter extending along the border of the caudal triangle, the *tenia medullaris inferior*. The tenia medullaris is continued laterally and affords a line of attachment for the tela chorioidea inferior in forming the evagination of the lateral recesses. The roof of the cephalic angle of the ventricle is formed by the *superior medullary velum*, upon which rests the lingula of the cerebellum. Certain portions of the inferior vermis of the cerebellum project into the ventricle; these are the nodule and a part of the uvula.

FEATURES IN THE FLOOR OF THE FOURTH VENTRICLE. The floor of the fourth ventricle is divided into two symmetrical halves by a median sulcus which runs from the apex of the lower triangle to the apex of the upper triangle. A second sulcus starts beneath the obex, lateral to the median sulcus, and proceeds cephalad, forming a curve which follows the lines of the lateral walls. It is situated about midway between the median sulcus and the lateral walls. This is the *sulcus limitans* which divides the floor of the ventricle into a mesial motor portion derived from the basal plate, and a lateral sensory portion derived from the alar plate. The most minute description of the ventricular floor has been given by Streeter, whose measurements of the several structures are here quoted.

In the caudal triangle, immediately adjacent to the median sulcus, is a long, narrow elevation, 5.2 mm. in length, and 1. mm. in width. This is the *eminentia hypoglossi*, which indicates the rounded, frontal end of the hypoglossal nucleus. The remainder of the hypoglossal nucleus is covered by other structures, its entire length being 12.2 mm. The intraventricular portion of the nucleus is 7. mm. long.

Cephalad of the eminentia hypoglossi, and upon either side of the median sulcus, is a less prominent elevation formed by the *nucleus funiculi teretis*. This measures 5.7 mm. by 1. mm. The eminence formed by this nucleus varies in different specimens, according to the arrangement of the striæ acousticæ, which have their medial terminations in this area. It has been suggested that there may be a relation between the nucleus funiculi teretis and the striæ acousticæ.

In a position lateral to the nucleus funiculi teretis and the nucleus hypoglossi is an elongated and wedge-shaped elevation caused by the presence of the *nucleus intercalatus*. This measures 12. mm. by 2.2 mm. at its greatest width. Many fine grooves cross this nucleus, especially along its mesial and lateral borders, giving it the appearance of a feathered region, which is therefore called the *area plumiformis*. This wedge-shaped nucleus itself extends from the striæ acousticæ to the tip of the calamus scriptorius.

Lateral to the nucleus intercalaris is the *fovea inferior* or *fovea vagi*, also

known as the *ala cinerea*. This area presents the middle third of the dorsal vago-glossopharyngeal nucleus, which in large part lies in the floor of the fourth ventricle. The entire dorsal vago-glossopharyngeal nucleus is 13.5 mm. long and averages 2. mm. in width. Cephalad of the fovea inferior, the dorsal nucleus of the vagus lies concealed beneath the vestibular nuclei. The lateral boundary of the fovea vagi is formed by the sulcus limitans, while its lateral edge is a slightly elevated cord-like ridge, the *funiculus separans of Retzius*.

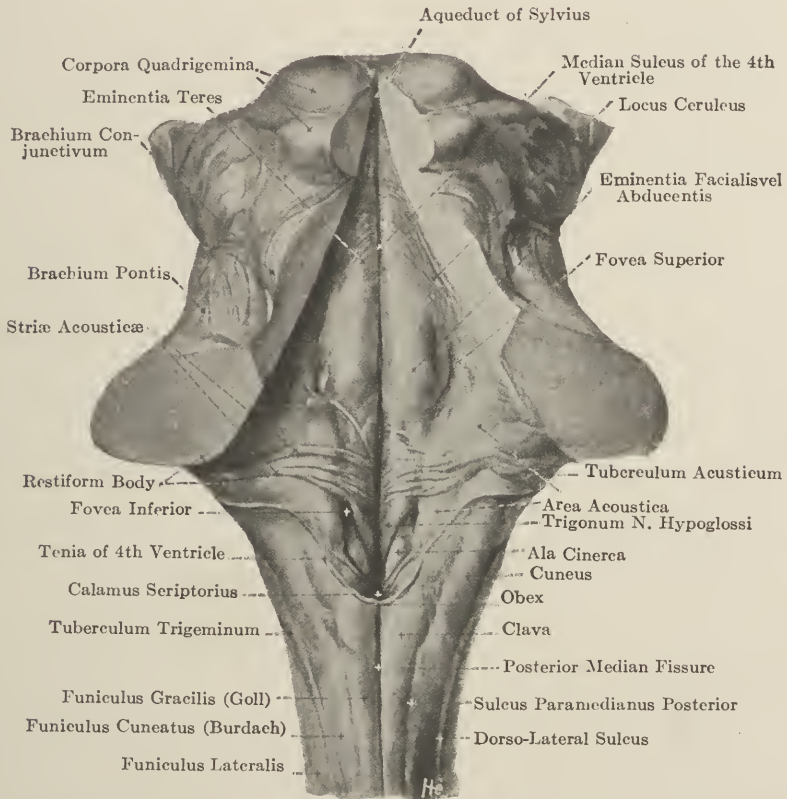


FIG. 276.—The fourth ventricle viewed from behind. The cerebellum and the chorioid plexus of the fourth ventricle have been completely removed; the brachia conjunctiva with the velum medullare anterius and the lamina quadrigemina have been partly cut away. (*Spalteholz.*)

Lateral and dorsal to the funiculus separans is the *area postrema*, whose boundaries are the tenia medullaris and the funiculus separans. This area extends forward without sharp line of demarcation into the region lying immediately cephalad to it, the *area acustica*.

All that portion of the floor of the ventricle, in both the caudal and cephalic triangles, which lies lateral to the sulcus limitans, belongs to the acoustic area. This area consists of a mesial or vestibular field and a lateral or cochlear field. The vestibular field forms an irregular shaped elevation

measuring 16.1 mm. by 4.5 mm., which extends from the *fovea superior* (*fovea trigemini*) to the *nucleus funiculi gracilis*. The floor of the fourth ventricle is traversed at the line marking the union of the bases of the two triangles by a number of transverse fibers which enter at either lateral recess. These are the *striæ acusticæ*. They usually extend transversely across the floor of the ventricle in the position mentioned, and terminate in the median sulcus into which they dip downward. They are, however, inconstant in this relation, oftentimes running obliquely cephalad, or quite as frequently obliquely caudad.

Immediately cephalad of the transverse fibers of the *striæ acusticæ* and adjacent to the median sulcus, is a rounded elevation 4. mm. in diameter, which is formed by the genu of the facial nerve encircling the nucleus abducens. This is the *eminentia facialis*. Partly overlapping this elevation and extending forward to the aqueduct of Sylvius is a longitudinal elevation consisting of scattered nerve fibers with scattered groups of small or medium-sized multipolar cells. Since its function is unknown, it is called the *nucleus incertus*. Situated between the two nuclei, on either side of the median sulcus, is a shallow depression measuring 5.7 mm. by 1. mm. in diameter, the *fovea mediana*. The fasciculus longitudinalis posterior here lies immediately beneath the floor of the ventricle, covered by a thin layer of central gray matter. In a position lateral to the nucleus incertus is an elongated depression in the floor of the ventricle 3.2 mm. in its greatest width, which becomes narrower as it extends cephalad. This is the *fovea trigemini* or *fovea superior*.

Cephalad of the superior fovea is the *locus ceruleus*, which continues for some distance into the aqueduct of Sylvius. It owes its color to the pigment cells constituting a large portion of the area, on account of which this region is referred to as the *substantia ferruginea*.

CHAPTER XXI

THE PONS VAROLII

INTERNAL STRUCTURE AND HISTOLOGY OF THE PONS

The transition from medulla oblongata to pons with the changes in the internal pontile structure are best appreciated by means of cross sections at five successive levels.

1. Through the caudal limit of the pontile fibers.
2. Through the caudal limit of the trapezoid or cochlear decussation.
3. Through the level of the caudal limit of the genu of the facial nerve.
4. Through the level of the nucleus masticatorius.
5. Through the level of the decussation of the trochlear nerve.

The description of the internal structure of the pons includes the arrangement of the gray and white matter in the two major portions of this division of the brain, namely, the tegmentum, or *pars dorsalis pontis*, and the basis, or *pars basilaris pontis*.

Arrangement of the Gray and White Matter at the Level of the Caudal Pontile Fibers. THE GRAY MATTER IN THE TEGMENTUM (*pars dorsalis pontis*). 1. *The Central Gray Matter.* At this level the central gray matter shows a slight inclination from either side toward the median sulcus. The ventricular floor here has its greatest transverse extent. Beginning in the median sulcus, the central gray matter contains the *nucleus funiculi teretis*, a collection of small and medium-sized cells. Lateral to this nucleus is the cephalic limit of the nucleus prepositus hypoglossi, while occupying a large adjacent triangular area is the *nucleus vestibularis triangularis* of Schwalbe. At the extreme lateral boundary of the ventricular floor is another vestibular nucleus containing cells somewhat larger than those found in the triangular nucleus, the *nucleus angularis* of Bechterew.

2. *The Reticular Formation.* The white and gray portions of the reticular formation occupy the central portion of the tegmentum. At the ventro-lateral extremity of the formatio reticularis alba is the large *nucleus facialis*, dorso-lateral to which is the substantia gelatinosa, much reduced in size. Situated in the raphé about midway between the floor of the ventricle and the ventral surface of the pons is the *nucleus centralis inferior*. There are no new elements in the gray matter of the tegmentum at this level.

THE WHITE MATTER IN THE TEGMENTUM. 1. *The Ventral White Column.* As in the medulla, the ventral white column contains the col-



FIG. 277.—Cross section through the pons at the caudal level of the pontile fibers. (Serial section No. 539.)

lected fibers of the mesial fillet and the fasciculus predorsalis. The fasciculus longitudinalis posterior lies immediately beneath the nucleus funicularis teretis.

2. *The Lateral White Column.* The central tegmental tract is still situated near the center of the tegmentum, while lateral to it are the descending root of the fifth nerve, the rubro-spinal, the spino-thalamic and the ventral spino-cerebellar tracts. The circumferential zone in the strict sense no longer exists, for the reason that the transverse fibers of the pons have already taken up a circumferential position. The fasciculi which make up the inferior cerebellar peduncle constitute a massive structure situated in the dorso-lateral portion of the pons.

ARRANGEMENT OF THE WHITE MATTER IN THE BASIS (*pars basilaris pontis*). A large collection of transverse fibers in a compact bundle sweep from one side to the other across the ventral surface of the tegmentum. They appear to be suspended from the dorso-lateral portion of the brain-stem and to be made up of axones passing from one side to the other. These transverse fibers constitute the *stratum superficiale pontis*, the most superficial layer of fibers found in this part of the brain. Dorsally, this collection of fibers is in contact with the ventral surface of the pyramids.

EMERGENT AND ENTRANT ROOT FIBERS. At this level, the more cephalic fibers of the cochlear division of the eighth nerve are in connection with the ventral cochlear nucleus, while the vestibular fibers of the eighth nerve are making their way toward the nucleus of Schwalbe and nucleus of Bechterew.

Emergent fibers arising in the facial nucleus appear in the *first part and fourth part* of their course. Axones from the nucleus project dorsally and mesially, as if making their way to the floor of the fourth ventricle. As they leave the nucleus they are not collected into a dense bundle but have the appearance of a loose fasciculus extending toward the nucleus prepositus hypoglossi.

Arrangement of the Gray and White Matter at the Level of the Caudal Limit of the Trapezoid Decussation. THE GRAY MATTER IN THE TEGMENTUM. 1. *The Central Gray Matter.* At this level the central gray matter is much reduced in size and the ventricle is decreased in all diameters. Its floor is much less extensive than in the preceding section, and its lateral walls consist of some of the fibers of the middle and superior cerebellar peduncles, but are made up mainly by fibers of the superior cerebellar peduncle. The roof of the ventricle contains the *nucleus tecti*. The general outline of the ventricle in cross section is oval. The nodule of the inferior cerebellar vermis projects into it.

The central gray matter in the floor of the ventricle is reduced in extent. Immediately adjacent to the median sulcus is the nucleus funicularis teretis, which overlies the caudal extremity of the nucleus abducentis. Lateral to this collection of cells is the nucleus vestibularis triangularis of Schwalbe, and in the most lateral position of the floor of the fourth ventricle is the nucleus angularis of Bechterew.

2. *The Reticular Formation.* The reticular formation contains the large *formatio reticularis grisea* and the somewhat reduced *formatio reticularis alba*. In the gray portion of the reticular formation, a new nucleus has made its appearance, the *nucleus reticularis tegmentis*, ventro-lateral to which is another new element, the *nucleus olivaris superior*. The *substantia gelatinosa* is reduced in size and lies dorso-lateral to the *nucleus facialis*.

THE GRAY MATTER IN THE BASIS PONTIS. The appearance of the pons at this level differs considerably from that noted in the preceding section. Among the transverse fibers is interposed a large collection of gray matter constituting the *pontile nuclei* (*nuclei pontis*). This is an extensive nucleus which serves as a relay for the fibers reaching the pons from the cerebral cortex and which, after synapsis, form part of the *crossed pallio-cerebellar pathway*.

THE WHITE MATTER IN THE TEGMENTUM. *The Ventral White Column.* The previous dorso-ventral relation existing in the tracts of the ventral white column has undergone considerable change. The pyramid, the most ventral of these tracts, has severed its connection with the tegmentum and has taken up a position in the pons. The mesial fillet has been collected into a triangular bundle and shows a tendency in some of its most ventral fibers to move into a lateral position; it has the appearance of an inverted letter V, which, due to pressure upon its apex, is gradually flattening out so that its two arms pass from an oblique to a horizontal position. The dorsal limit of the mesial fillet is separated by a considerable distance from the next dorsal element, the *fasciculus predorsalis*, which, together with the *fasciculus longitudinalis posterior*, occupies its usual area near the floor of the fourth ventricle. The *nucleus funiculi teretis* covers the dorsal surface of the *fasciculus longitudinalis posterior*.

2. *The Lateral White Column.* At this level the central tegmental tract is still present, mesial to the facial nucleus and lateral to the *nucleus reticularis tegmenti*. Dorso-lateral to the superior olive are the spino-thalamic, the rubro-spinal and the ventral spino-cerebellar tracts. The descending root of the fifth nerve occupies a position lateral to the much reduced *substantia gelatinosa*. An important new element in the white matter at this level is the beginning of the *trapezoid* or *cochlear decussation*. Its fibers arise in the superior olive, make their way ventral to and through the mesial fillet to the *raphé*, where they undergo a complete decussation. This constitutes the beginning of the *trapezoid decussation*.

THE WHITE MATTER IN THE BASIS PONTIS. The white matter in the basal portion of the pons consists of the transverse fibers forming the *stratum superficiale pontis*.

EMERGENT AND ENTRANT ROOT FIBERS. Some of the emergent fibers of the sixth nerve are about to make their way from the tegmentum into the basis. In this course they traverse the mesial fillet and pass between the fasciculi of the pyramidal tract. This constitutes the second portion in the emergent course of the sixth nerve. It marks a locality in the brain-stem

where injury or disease may simultaneously affect the abducens nerve, the mesial fillet and the pyramidal tract, as well as fibers in the secondary



FIG. 278.—Cross section of the pons through the caudal level of the trapezoid decussation. (Serial section No. 595.)

cochlear pathway. Two portions of the seventh nerve appear at this level, the first part consisting of scattered fasciculi emerging from the nucleus and

proceeding dorso-mesially toward the floor of the ventricle, and the *fourth part*, representing the last stage of its emergent course. The collected mass of the vestibular division of the eighth nerve is also seen coming into relation with the vestibular nuclei and entering into the formation of the descending vestibular root.

Arrangement of the Gray and White Matter at the Level of the Genu of the Facial Nerve. **THE GRAY MATTER IN THE TEGMENTUM.** The central gray matter in the floor of the ventricle is further reduced in size, while its lateral boundary is now the superior cerebellar peduncle. The most prominent structure at this level is the nucleus funiculi teretis which projects into the ventricle as a large eminence caused by the presence of the nucleus abducentis. Lateral to this prominence are the nucleus vestibularis triangularis of Schwalbe and the nucleus angularis of Bechterew. The reticular formation contains a fairly large gray portion and a somewhat smaller white portion. The nucleus reticularis tegmenti has increased in size and is situated adjacent to the raphé upon either side. The superior olive is still present and is somewhat enlarged. Mesial to it is the *nucleus trapezoideus*, a part of the relay system of the cochlear division of the eighth nerve. The substantia gelatinosa is reduced in size and lies mesial to the entrant root fibers of the fifth nerve.

THE GRAY MATTER IN THE BASIS PONTIS. The gray matter of this portion of the pons is much more extensive, consisting of the large pontile nucleus which is interspersed among the transverse pontile fibers.

THE WHITE MATTER IN THE TEGMENTUM. The white matter has undergone marked alteration. It has lost one of its chief elements, the pyramid, which occupies a more ventral position in the pons. The mesial fillet forms the most ventral structure in the tegmentum and is also changed in shape and arrangement; its long axis extends transversely from one side of the section to the other. Dorsal to the fillet are the nucleus reticularis tegmenti, the fasciculus predorsalis and the fasciculus longitudinalis posterior. The latter bundle is in close relation with the second portion of the emergent root fibers of the seventh nerve, which, in combination with the nucleus abducentis, produce a bulging in the floor of the fourth ventricle, the *eminentia abducentis*.

The lateral white column contains the central tegmental, rubro-spinal, spino-thalamic and ventral spino-cerebellar tracts, as well as the descending root of the fifth nerve. A collection of horizontal fibers from the superior olive to the nucleus abducens constitutes the *peduncle of the inferior olive*, which serves as a reflex connection, causing the eyes to turn in the direction of sounds received by the ear. In the lateral white column adjacent to the extremity of the mesial fillet is a collection of fibers making an ascending course; these constitute the *lateral fillet* and represent the fibers which cross in the trapezoid decussation to form the secondary connection in the cochlear pathway. Another group of fibers situated in the dorso-mesial portion of the lateral white column are the *striæ acusticæ profundæ* which take origin in

the dorsal cochlear nucleus and make their way to the trapezoid decussation.

THE WHITE MATTER IN THE BASIS PONTIS. The pons consists of two

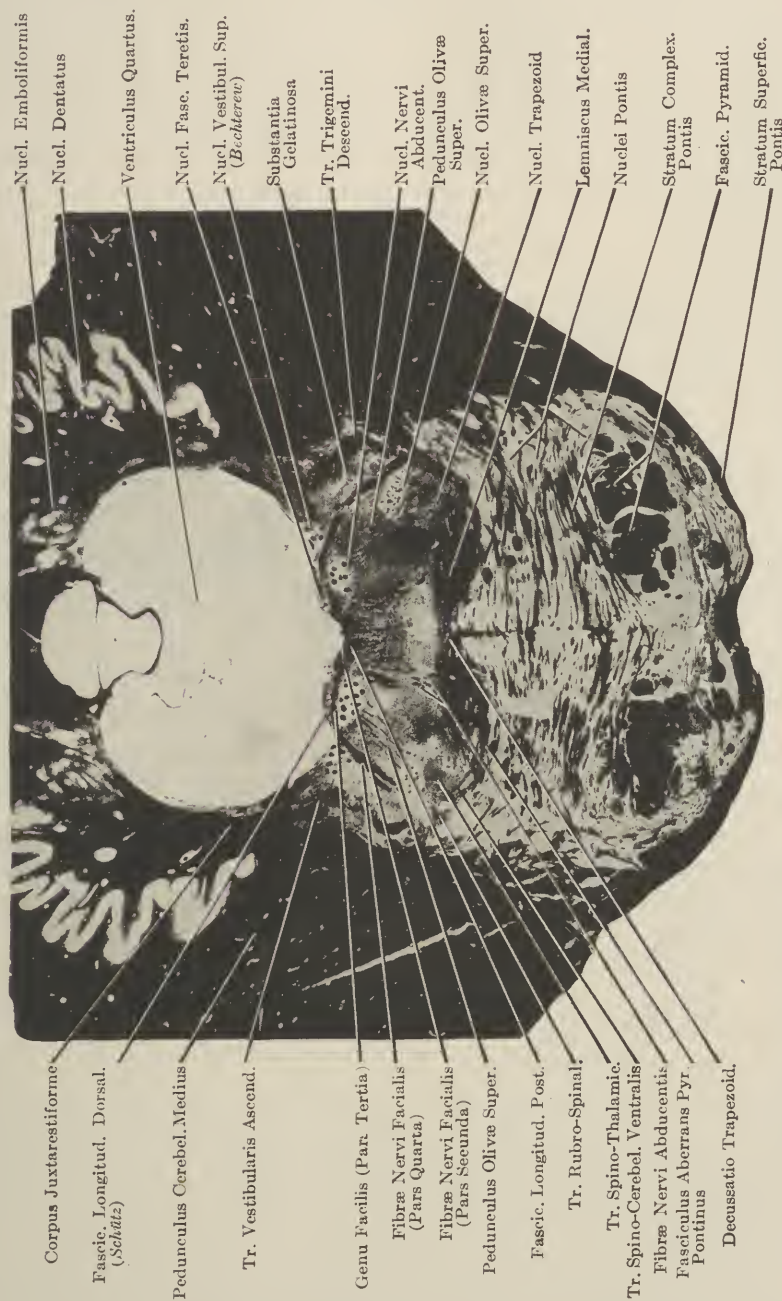


FIG. 279.—Cross section through the pons at the level of the facial genu. (Serial section No. 609.)

groups of transverse fibers, the *stratum superficiale pontis* and the *stratum profundum pontis*.

EMERGENT AND ENTRANT ROOT FIBERS. The first portion of the sixth nerve makes its way from its nucleus through the tegmentum and the mesial fillet. The second and fourth parts of the seventh nerve are present at this level, the second part lying dorsal to the fasciculus longitudinalis posterior. The third portion or genu of the seventh nerve passes around the nucleus of the sixth nerve, making its way outward to the fourth portion.

Arrangement of the Gray and White Matter at the Level of the Nucleus Masticatorius. **THE GRAY MATTER IN THE TEGMENTUM.** 1. *The Central Gray Matter.* The central gray matter is much reduced in size and the floor of the ventricle is decreased in its transverse diameter. The lateral boundary of the ventricle is formed by the superior cerebellar peduncle. The nuclear elements in the floor of the ventricle have diminished in size and number. Adjacent to the median sulcus, which has become somewhat broader to form the fovea mediana, is a collection of small and medium sized cells, the *nucleus incertus*. Ventral to the nucleus of Schwalbe is a collection of large motor cells which give rise to the motor division of the trigeminal nerve, the *nucleus masticatorius*.

2. *The Reticular Formation.* The reticular formation contains a large central griseal portion and a small white portion. Adjacent to the raphé is the large nucleus reticularis tegmenti and still further lateral is the cephalic extremity of the superior olive and the much reduced substantia gelatinosa.

THE GRAY MATTER IN THE BASIS PONTIS. The gray matter at this level of the pons is much increased in the size and richness of the pontile nuclei.

THE WHITE MATTER IN THE TEGMENTUM. 1. *The Ventral White Column.* This column consists of the mesial fillet, dorsal to which is the nucleus reticularis tegmenti, the fasciculus predorsalis and the fasciculus longitudinalis posterior. The latter bundle is situated ventral to the second part of the seventh nerve, which is turning into the third part of its course to form the genu facialis. This bundle of fibers is situated beneath the nucleus incertus. The facial nerve arises from a nucleus caudal to the nucleus abducens, and sends its first part as a spray of fibers toward the floor of the fourth ventricle, where it passes into the second part of its course as a collected bundle of fibers. This bundle makes its way mesial to the abducens nucleus beneath the floor of the ventricle to the cephalic extremity of the nucleus of the sixth nerve. Here it turns transversely outward beneath the floor of the ventricle to form the third part of its course, the genu of the seventh nerve. The bundle of facial fibers finally turns ventrally and caudally, to emerge from the bulbo-pontile sulcus in close relation to the two divisions of the eighth nerve.

2. *The Lateral White Column.* This column contains the central tegmental, the rubro-spinal, the spino-thalamic, the ventral spino-cerebellar tracts, and the beginning of the descending root of the fifth nerve.

THE WHITE MATTER IN THE BASIS PONTIS. In addition to the

stratum superficiale pontis and the stratum profundum pontis, another group of transverse fibers has interposed itself in the pons. This is the *stratum complexum pontis*. These crossing fibers pass in and out

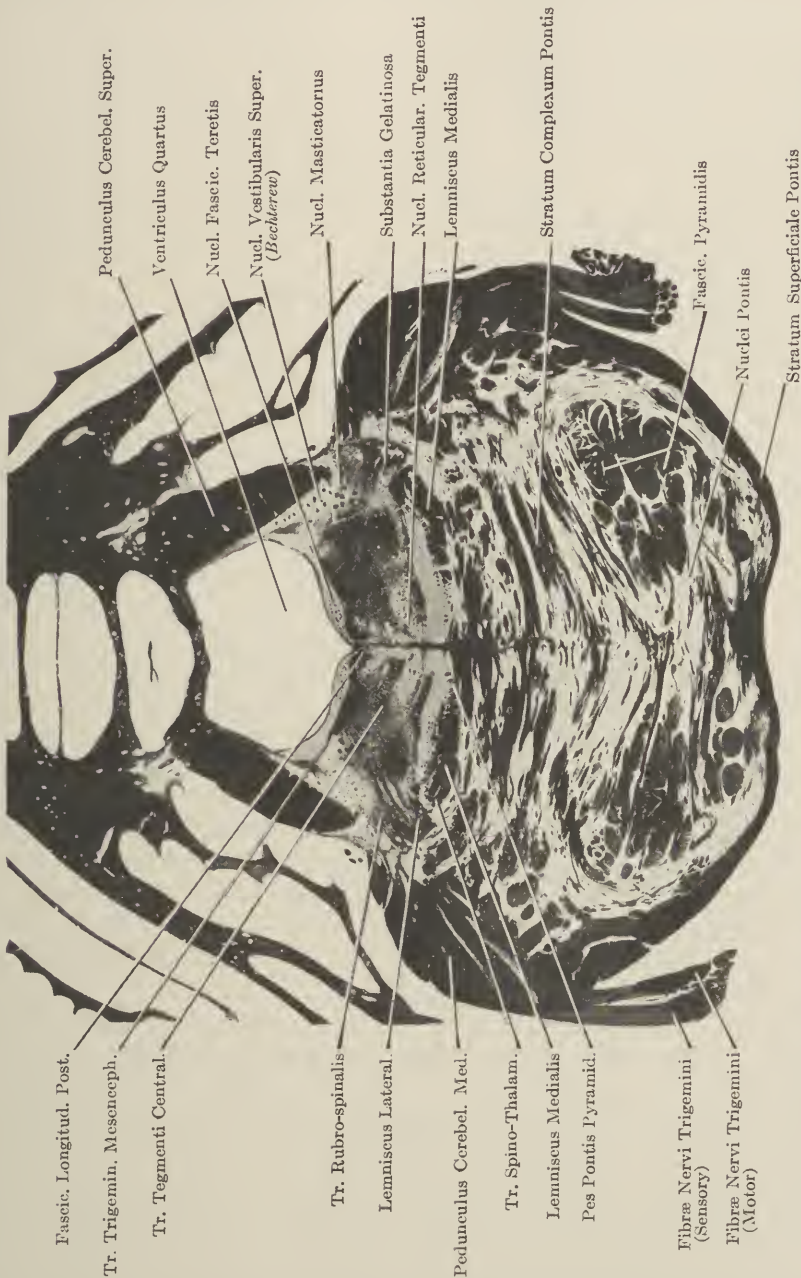


FIG. 280.—Cross-section through the pons at the level of the masticatory nucleus. (Serial section No. 671.)

between the several fasciculi of the pyramidal system, subdividing it into a number of smaller, separate groups of fibers.

Near the junction of the stratum profundum and the tegmentum, a number of pyramidal fibers pass dorsally as if about to enter the tegmentum of the pons. These fibers constitute the *pontile contingent of the aberrant pyramidal system* and serve to carry volitional impulses to the nuclei of the fifth, tenth, and twelfth cranial nerves. After leaving the stratum profundum, the fibers of the aberrant pyramidal system become incorporated with those of the mesial fillet.

EMERGENT AND ENTRANT ROOT FIBERS. The chief nerve roots at this level are the emergent fibers of the facial nerve.

Arrangement of the Gray and White Matter at the Level of the Decussation of the Trochlear Nerve. **THE GRAY MATTER IN THE TEGMENTUM.**

1. *The Central Gray Matter.* The central gray matter surrounds the ventricle, which has been reduced to a small triangular cavity. In the floor of the ventricle the central gray matter is arranged as two lateral masses extending obliquely up to the roof-plate. The roof consists of the superior medullary velum through which pass the decussating fibers of the *trochlear nerve*, the only motor nerve which undergoes complete decussation before its emergence from the brain-stem. Beneath the median sulcus, the central gray matter contains the *nucleus dorsalis raphé*, lateral to which is a collection of large motor cells having a bluish or brownish color, the *locus ceruleus*. Ventral to these cells are some large gryochrome elements intermingled in part with those of the locus ceruleus, which constitute the mesencephalic nucleus of the trigeminal nerve. Dorsal to the locus ceruleus is the descending portion of the trochlear nerve. In their emergent course the fibers of the fourth nerve descend to this level, make a sharp dorsal curve, reach the superior medullary velum and pass inward across the median line, where they meet the corresponding fibers from the opposite side. After this decussation the trochlear nerve emerges from the lateral margins of the superior medullary velum.

2. *The Reticular Formation.* The reticular formation has been subdivided into a lateral and a mesial portion by the ventro-mesial migration of the superior cerebellar peduncle, which is assuming a position preparatory to its decussation. The mesial portion of the reticular formation contains the *formatio reticularis grisea*. In the center of the tegmentum on either side of the raphé is the *nucleus centralis superior*.

THE GRAY MATTER IN THE BASIS PONTIS. There is an increase in the size of the pontile nucleus, but no new elements have made their appearance at this level.

THE WHITE MATTER IN THE TEGMENTUM. 1. *The Ventral White Column.* It is difficult to recognize the limits of a ventral white column, since many changes have occurred in the arrangement of the ascending and descending tracts. The ventral column is occupied by the mesial fillet which now lies directly transversely across the brain-stem, although it shows some tendency for its lateral portion to turn into a more dorsal position. In the circumferential zone there is a thin layer of gray matter, immediately mesial

to which are the following tracts: The ventral spino-cerebellar tract, which at this point is turning backward to cross the lateral surface of the superior

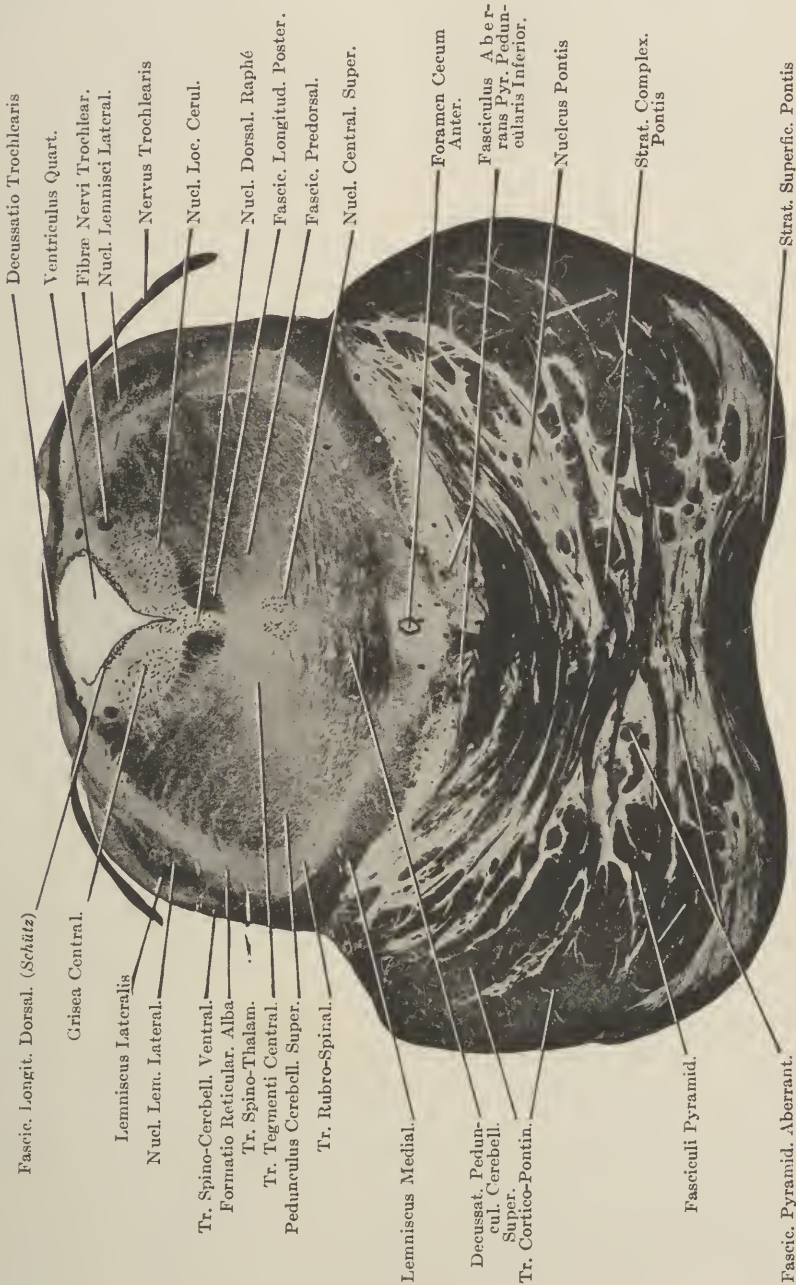


FIG. 281.—Cross section through the pons at the level of the trochlear decussation. (Serial section No. 691).

cerebellar peduncle on its way to the cerebellum; the lateral fillet or secondary cochlear pathway; ventral to the lateral fillet is a narrow strip of white

matter which contains the spino-thalamic tract; immediately dorsal to the lateral extremity of the mesial fillet is the rubro-spinal tract. All of these tracts are arranged in the form of the letter L, the vertical limb being represented by the lateral fillet and the spino-thalamic tract, while the horizontal limb contains the rubro-spinal tract and the mesial fillet.

Interspersed among the fibers of the mesial fillet, and occupying a position at its mesial extremity, are fibers of a different category from those constituting the bulk of the mesial fillet itself. These are descending fibers which have become associated secondarily with the fillet. They descend originally in relation with the pyramidal tract and represent the pyramidal fibers designed to bring volitional control to certain of the cranial nerve nuclei.

Mesial to the circumferential zone is the ventral portion of the reticular formation, the mesial boundary of which is the superior cerebellar peduncle. Many fibers of the superior cerebellar peduncle pass inward toward the median line preparatory to their decussation in the midbrain. The circumgriseal portion borders upon the formatio reticularis grisea, near the center of which courses the central tegmental tract and, in a more mesial position, the fasciculus predorsalis. Beneath the central gray matter, on either side of the median line, are the collected fibers which form the fasciculus longitudinalis posterior. Lying immediately beneath the ependyma lining the ventricle are the fibers of the fasciculus longitudinalis dorsalis of Schütz.

THE WHITE MATTER IN THE BASIS PONTIS. The arrangement of the transverse fibers of the pons is similar to that in the preceding section, although the stratum complexum pontis has become more complicated and has caused a further separation in the individual fasciculi of the pyramidal tracts. The stratum profundum has about disappeared, and the stratum superficiale is much reduced in its dimensions. The connection of the pons fibers with the middle cerebellar peduncle is not evident at this point, as the section carries the plane through the brain-stem at a point cephalad to the level of the peduncle.

EMERGENT ROOT FIBERS. The only nerve roots connected with this level of the brain-stem are the emergent fibers of the nervus trochlearis, which, after complete decussation in the superior medullary velum, emerge in a manner dissimilar to that of any other of the cranial nerves. The reason for this decussation in a motor nerve controlling one of the eye muscles, as well as for its aberrant course and emergence, is not clear. This region of the brain-stem connected with the emergence of the trochlear nerve has been referred to as the *isthmus metencephali*.

Summary of the Relations of the Gray and White Matter of the Pons Varolii. Cross sections through the pons show many changes as compared with the spinal cord and the medulla. These changes are occasioned by the appearance of certain elements not observed in other parts of the brain, as well as by the disappearance of several familiar landmarks. The principal change is the addition of the transverse pontile fibers constituting the pars basilaris pontis, together with the appearance of the extensive pontile

nuclei. The distinction between the basis and the tegmentum of the pons is clearly indicated, but it is no longer possible to recognize dorsal, lateral or ventral gray columns. The central gray matter, however, retains a general resemblance to the conditions observed in the medulla oblongata.

FEATURES OF THE METENCEPHALIC GRAY AND WHITE MATTER. Certain features of the gray and white matter are especially characteristic of the metencephalon. The following are the principal characters in the gray matter:

1. The nucleus facialis.
2. The nucleus abducens.
3. The nucleus masticatorius (motor nucleus of the fifth nerve).
4. The vestibular nuclei of Bechterew and Schwalbe (nucleus angularis vestibularis, nucleus triangularis vestibularis).
5. The nucleus of the superior olive (superior olive).
6. The nucleus trapezoideus.
7. The pontile nuclei.
8. The mesencephalic nucleus of the trigeminal nerve.
9. The nucleus of the lateral fillet.

The following features are characteristic of the white matter in the metencephalon:

1. The three strata of pontile fibers, including the stratum superficiale, the stratum profundum and the stratum complexum.
2. The middle cerebellar peduncle.
3. The rearrangement of the mesial fillet from a dorso-ventral to a transverse position.
4. The appearance of the aberrant pyramidal fibers in connection with the mesial fillet.
5. The superior cerebellar peduncle.
6. The appearance of the lateral fillet.
7. The dorsal shift of the ventral spino-cerebellar tract.
8. The maintenance of the rubro-spinal and spino-thalamic tracts in positions corresponding closely to those occupied by these fasciculi in the spinal cord.

This part of the brain presents three principal decussations:

1. The trapezoid decussation. The decussation of the trapezoid body or crossing in the secondary pathway of hearing.
2. The complete decussation of the trochlear (fourth cranial nerve) in the superior medullary velum.
3. The complete decussation of the pallio-cerebellar pathway.

NERVES CONNECTED WITH THE PONS. Five of the cranial nerves are connected with the pons Varolii.

1. The trochlear nerve makes part of its descending intra-axial course and undergoes decussation in this region of the brain.
2. The trigeminal nerve has its motor nucleus and the cephalic extremity of its sensory receiving nucleus in the metencephalon.
3. The abducens nerve has its nucleus in the metencephalon; its emer-

gent fibers pass through both the tegmental and basal portions of the pons before emerging.

4. The facial nerve has the major portion of its motor nucleus and the cephalic extremity of its sensory receiving nucleus (the nucleus fasciculus solitarius) in the metencephalon. All four portions of the emergent fibers of the seventh nerve make their way through this part of the brain-stem. This includes: the first part, consisting of diffuse axones; the second part, mesial to the nucleus abducens and forming part of the eminentia abducentis in the floor of the fourth ventricle; the third part, the genu of the nerve; and the fourth part, by means of which the nerve fibers descend from the genu and finally emerge from the bulbo-pontile sulcus in relation with the two divisions of the eighth nerve.

5. The vestibular division of the eighth nerve has important receiving nuclei in the metencephalon. The cochlear division of this nerve also receives a relay in the tegmental portion of the pons.

CHAPTER XXII

THE PONS VAROLII

FUNCTIONS AND PRINCIPAL SYNDROMES OF THE PONS

FUNCTIONS OF THE GRAY MATTER

The metencephalon acts in a complementary capacity to many of the functions of the medulla. Primitively the tegmentum of the myelencephalon and metencephalon constituted a common autonomous area essential to the regulation of the vital processes. This autonomous area still exists in man, although pontile structures have been added to it.

Splanchnic Motor Functions of the Pons.

1. Through the motor nucleus of the trigeminal nerve, the nucleus masticatorius, the pons innervates the following muscles of mastication through the portio minor of the trigeminal nerve: the temporal muscle, the masseter muscle, the external and internal pterygoid muscles, the mylohyoid muscle and the anterior belly of the digastric muscle.

It supplies glandular effector impulses to the salivary glands. In all probability, it innervates, in part at least, the lachrymal gland and also the sudoriferous and sebaceous glands of the face and fore part of the head.

2. Through the motor nucleus of the facial nerve, the pons innervates the following musculature: all of the muscles of expression, the intrinsic and extrinsic muscles of the external ear, the stylohyoid and posterior belly of the digastric muscle, the platysma myoides muscle, the stapedius muscle and perhaps some portion of the levator palati and azygos uvulæ muscles.

the remainder of the facial musculature. A lesion at *A* will, therefore, produce a voluntary paralysis of the contralateral lower facial nucleus, leaving intact the upper facial supply, whereas a lesion at *B* will produce a total unilateral seventh nerve paralysis.

a—Facial motor cortex. *b*—Cortico-nuclear fiber bundle establishing a crossed control. *c*—Cortico-nuclear fiber bundle establishing an uncrossed control. *d*—Decussation in the pontine tegmentum. *e*—Upper facial nucleus. *f*—Lower facial nucleus. *g*—Midline. *h*—Emergent facial nerve.

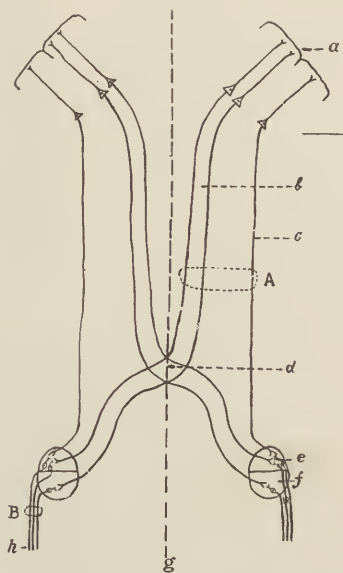


FIG. 281-A.—Diagram representing the bilateral cortical control of the seventh cranial nerve. Fibers are derived from both sides of the cortex for the supply of the upper facial nucleus. Fibers are derived from one side only, contralateral, for the supply of the lower facial nucleus. The upper facial nucleus supplies the occipito-frontalis, the corrugator

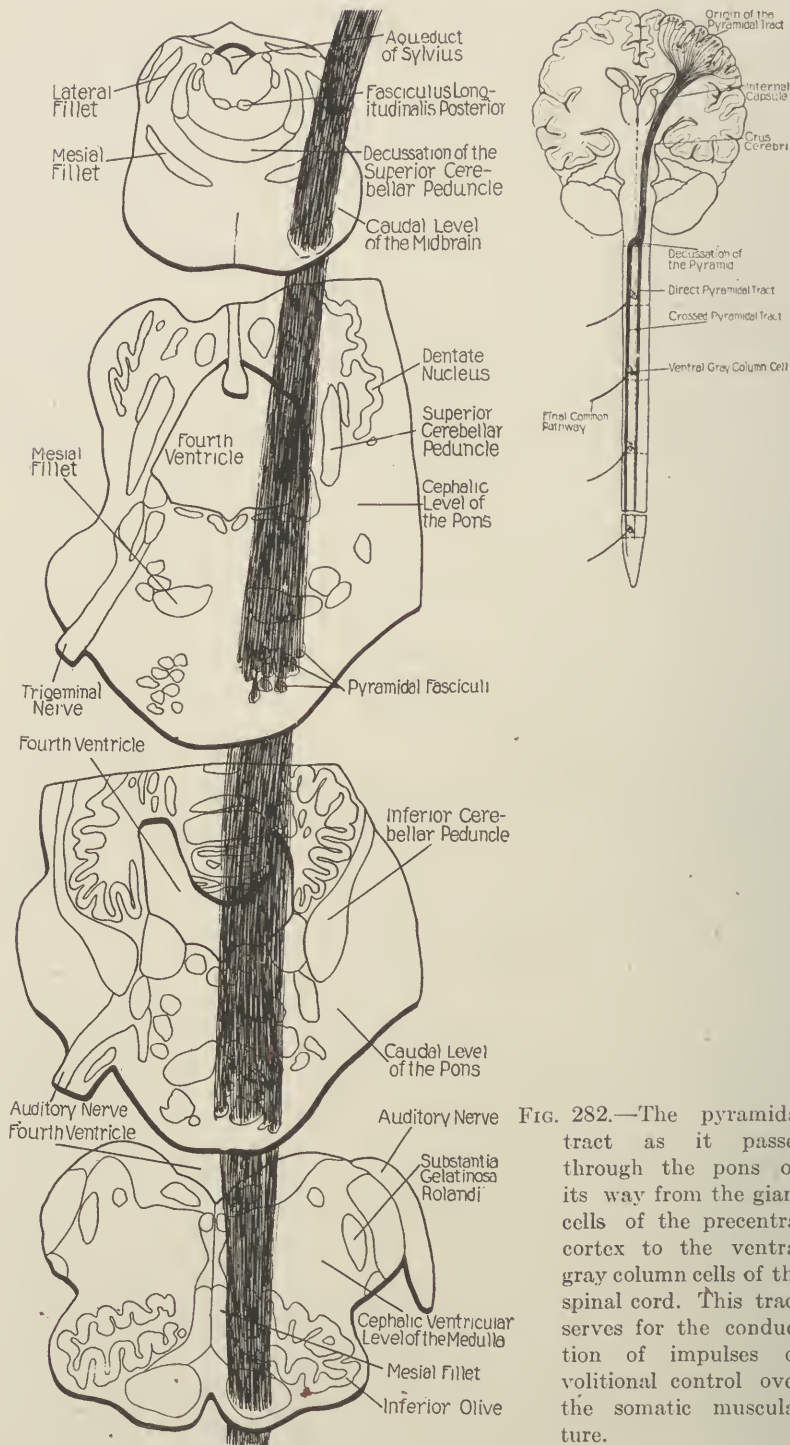


FIG. 282.—The pyramidal tract as it passes through the pons on its way from the giant cells of the precentral cortex to the ventral gray column cells of the spinal cord. This tract serves for the conduction of impulses of volitional control over the somatic musculature.

Through the seventh nerve, the pons contributes impulses to the sub-maxillary, sublingual and lachrymal glands.

Clinically, the most significant feature of the pontile innervation of the facial musculature is the fact that the muscles of expression are grouped in three divisions, namely, those in the upper, middle and lower face. Each division receives its nerve supply through a special branch of the facial nerve. When the facial nucleus is affected by disease or suffers from injury on one side, all of the muscles on the corresponding side of the face become paralyzed. This is also true if the nerve fibers constituting the facial nerve are injured or diseased. A complete paralysis of all the muscles on one side of the face is known as the *peripheral type of facial palsy*. This paralysis differs from that in which the connection of the facial nucleus with the cerebral cortex is defective in any part of its course from the origin in the motor area to the nucleus. Such a lesion produces a paralysis limited to the middle and lower facial muscles of the opposite side. The upper portion of the muscles of expression, the occipito-frontalis and the corrugator supercilli, remain normal. Paralysis of this kind is known as the *central or supra-nuclear type of facial palsy*. The explanation of the difference between the peripheral and central types of facial paralysis is that the cells in the facial nucleus supplying the upper facial muscles receive volitional control from both sides of the motor cortex, while the part which supplies the middle and lower facial muscles receives volitional control from the opposite side of the cortex only. A lesion in the pallio-nuclear connection of the seventh nerve would thus cause a paralysis of the middle and lower facial muscles of the opposite side. But since the nucleus is still receiving impulses from the other pallio-cortical connection for the upper facial muscles, these latter remain under the control of the will.

Splanchnic Sensory Functions of the Pons. The pons receives, by way of the *pars intermedia of Wrisberg*, the most cephalic fibers entering into the nucleus fasciculus solitarius. These fibers supply the sense of taste to the anterior two-thirds of the tongue.

Somatic Motor Functions of the Pons. Through the nucleus abducens, the pons innervates the external rectus muscle of the eye-ball. The nucleus supplying this muscle is, perhaps, the most important nuclear center in the control of the oculomotor mechanism, from the fact that it is the pacer-maker of eye movements, especially those in the horizontal plane.

Somatic Sensory Functions of the Pons. Through the large sensory nucleus which constitutes the cephalic portion of the substantia gelatinosa, whose caudal continuation extends into the medulla and the spinal cord, the pons innervates a portion of the front of the head, the face, part of the external ear, the nose and nasal cavity, the eye and orbit, the palate and nasopharynx in part, the tonsil, the cavity of the mouth, the tongue and a considerable portion of the dura mater lining the cranial cavity.

The pons also contains relay stations in the formation of the secondary tracts in the auditory pathway. These relay stations are found in the superior olivary nucleus and the nucleus trapezoideus. The vestibular division of the eighth nerve receives part of its relay in the pons Varolii.

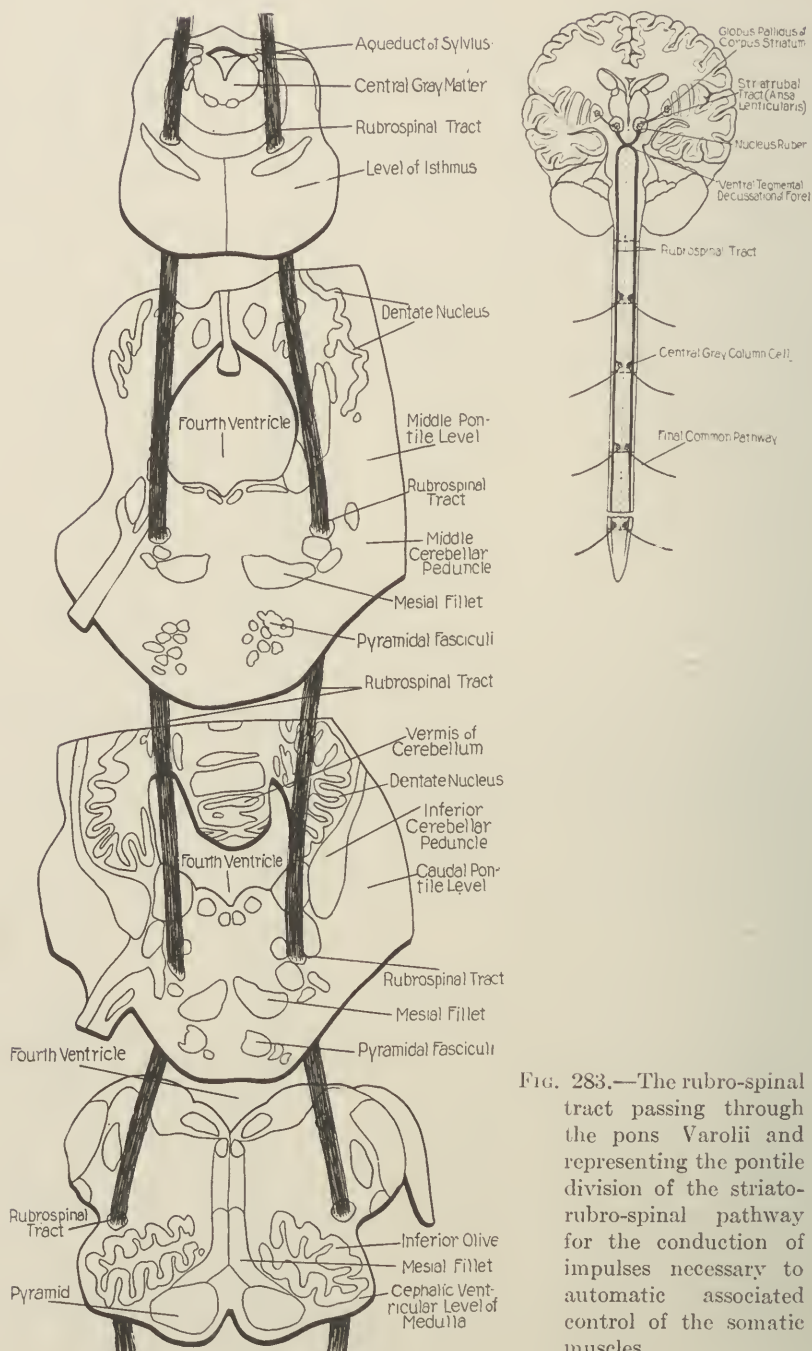


FIG. 283.—The rubro-spinal tract passing through the pons Varolii and representing the pontile division of the striato-rubro-spinal pathway for the conduction of impulses necessary to automatic associated control of the somatic muscles.

Simple Reflexes Mediated Through the Pons. 1. *The Mandibular Reflex.* This reflex is elicited by percussion over the chin, producing elevation of the lower jaw. The reflex depends upon an arc whose afferent arm is in the trigeminal nerve. The nucleus of reception is in the substantia gelatinosa, from which impulses are transmitted to the *nucleus masticatorius* whose efferent arm is the motor division of the trigeminal nerve.

2. *The Zygomatic Reflex.* This reflex of the lower jaw is elicited by percussion over the zygoma, which causes lateral motion to the same side. The reflex depends upon an arc whose afferent arm is in the trigeminal nerve. It is relayed in the substantia gelatinosa and connected by reflex collaterals to the nucleus masticatorius. Its efferent arm is the motor portion of the fifth nerve bearing the motor impulses to the masseter and temporal muscles of the same side.

3. *The Nasal Reflex of Bechterew.* This reflex is elicited by tickling the nasal mucosa with a feather or piece of paper which causes the contraction of the facial muscles upon the same side of the face. The reflex depends upon an arc whose afferent arm is in the trigeminal nerve, which bears the impulses to the substantia gelatinosa, transmitting them, by means of reflex collaterals, to the facial nucleus whose efferent arm, the facial nerve, brings the impulses to the muscles of expression of the same side.

4. *The Supra-Orbital Reflex of McCarthy.* This reflex is elicited by percussion over the supra-orbital ridge, which causes the closure of the eyelid upon the same side. The reflex depends upon an arc whose afferent arm is in the trigeminal nerve, which conveys the impulse to the substantia gelatinosa, from which it is transmitted by reflex collaterals to the nucleus of the facial nerve whose efferent arm, the facial nerve, conveys the impulse to the orbicularis palpebrarum.

5. *The Conjunctival Reflex.* This reflex is elicited by touching the conjunctiva over the cornea, which causes the closure of the eye-lid of the same side. The reflex depends upon an arc whose afferent arm is in the trigeminal nerve, which conveys the impulse to the substantia gelatinosa, whence it is transmitted to the nucleus of the facial nerve whose efferent arm, the facial nerve, conveys the impulse to the orbicularis palpebrarum muscle.

6. *The Lachrymal Reflex.* This reflex is elicited by touching the conjunctiva over the cornea, which causes the secretion of tears. The reflex depends upon an arc whose afferent arm is in the trigeminal nerve, which conveys the impulse to the substantia gelatinosa, whence it is transmitted to the cells controlling the glandular effector activities of the lachrymal gland. The efferent arm of the arc is probably through the great superficial petrosal nerve, which, after passing through the Vidian canal, comes into relation with the sphenopalatine ganglion and from that point reaches the lachrymal branch of the ophthalmic division of the fifth nerve.

7. *The Conjunctivo-Mandibular Reflex.* This reflex is elicited by touching the conjunctiva over the cornea, which causes a drawing of the lower jaw toward the side of the stimulation. The reflex depends upon an arc whose afferent arm is in the trigeminal nerve, which conveys the sensory impulse to the substantia gelatinosa, whence it is transmitted by reflex collaterals to

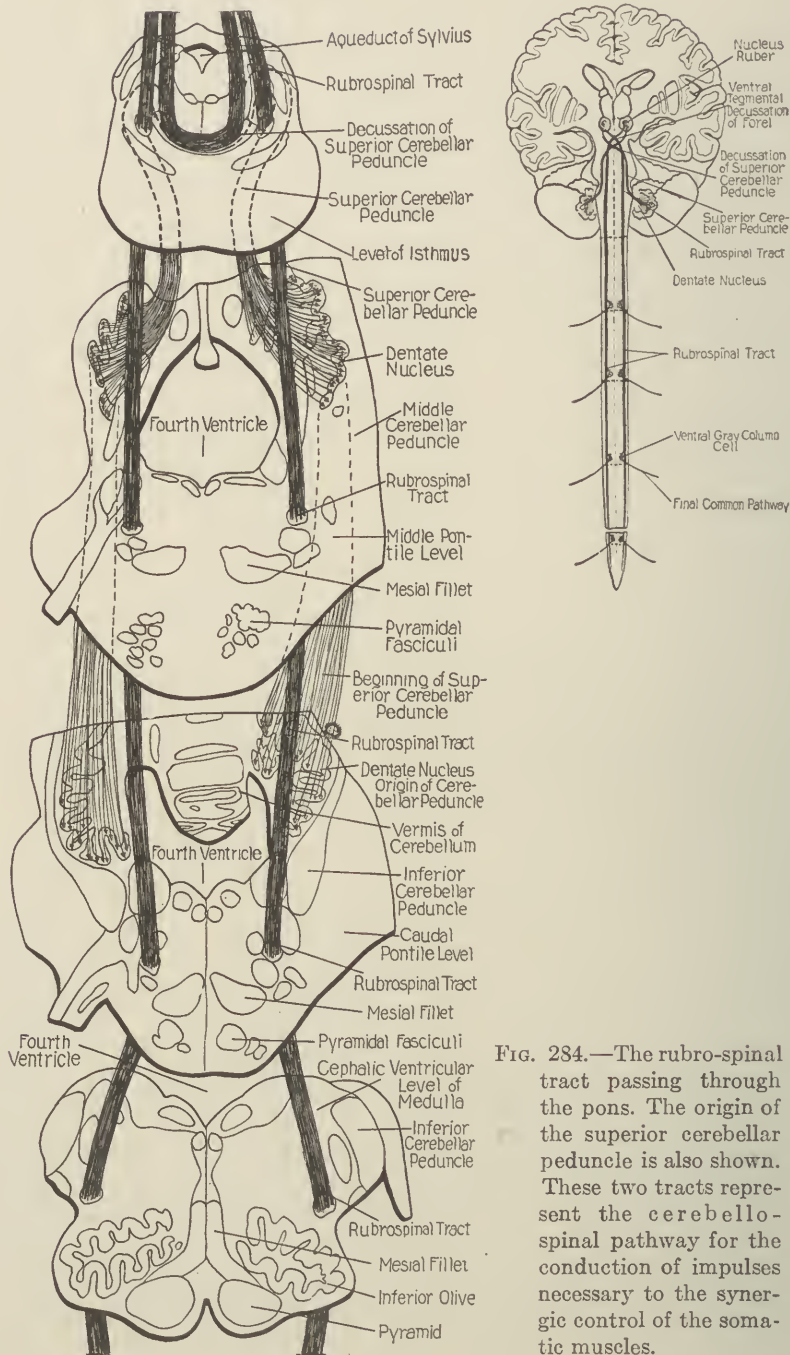


FIG. 234.—The rubro-spinal tract passing through the pons. The origin of the superior cerebellar peduncle is also shown. These two tracts represent the cerebello-spinal pathway for the conduction of impulses necessary to the synergic control of the somatic muscles.

the nucleus masticatorius of the same side. The efferent arm of this reflex is in the motor portion of the trigeminal nerve.

8. *The Auditory Reflex.* This reflex is elicited by any sudden sound which causes a momentary closure of both eyelids. The reflex depends upon an arc whose afferent arm is in the cochlear division of the eighth nerve, which conveys the sensory impulses to the general receiving station of the cochlear division, and then transmits them by reflex collaterals to the nucleus of the facial nerve whose fibers form the efferent arm to distribute the motor impulses to the orbicularis palpebrarum. Extension of this reflex, probably through the reticular formation, produces a change in respiration resulting in momentary inhibition. A further spread so influences the general body musculature as to bring the individual to a sudden standstill or to hold the body immobile for the instant.

9. *The Audito-Oculogyric Reflex.* This reflex is elicited by a sudden noise which causes a turning of both eyes in the direction of the sound. The reflex depends upon an arc whose afferent arm is in the cochlear division of the eighth nerve, which conveys the auditory impulses to the receiving station of the cochlear nerve, whence it is transmitted by reflex collaterals from the superior olivary nucleus to the abducens nucleus. These collaterals constitute the *peduncle of the superior olive*, and form a connection between the superior olivary nucleus and the sixth nerve. The efferent arm of the arc is in the fibers of the abducens nerve, which conveys the motor impulse to the external rectus muscle of the same side, and also to the opposite internal rectus muscle by means of the fasciculus longitudinalis posterior, thus producing a movement of lateral gaze in the direction of the sound.

The Pons in its Relation to Special Functions. Inasmuch as the pons is an auxiliary to the medulla in its tegmental portion, it serves in this capacity for the functions of respiration, phonation, deglutition and secretion. It does not, however, take part in the more exclusively vagal functions of the medulla, that is to say, in cardio-vascular control, or in the regulation of the gastro-intestinal canal.

THE PONS IN ITS RELATION TO RESPIRATION. By means of the trigeminal and facial nerves, the pons innervates the muscles which act in conjunction with the respiratory mechanism in order to prepare the upper air passages for the reception of the inspired air and the delivery of the expired air. In ordinary respiration, the pons, through the fifth nerve, closes the mouth by drawing the lower jaw upward and by a slight compression of the lips which is effected through the facial nerve. In this way it prepares the upper respiratory passage for inspiration, causing the inspired air to pass in through the nose in order that it may be sufficiently warmed and partially dehydrated if the atmosphere is chilly or humid. In active respiration, when the nasal passage is not sufficient to admit the volume of air required, this process is reversed, the mouth is held open by the fifth nerve and the anterior nares are dilated by the seventh nerve; so that the pons regulates the intake of air according to the needs of the individual.

In extremes of respiratory necessity, where there is marked dyspnea and gasping for air, the mouth is forcibly opened by depression of the lower

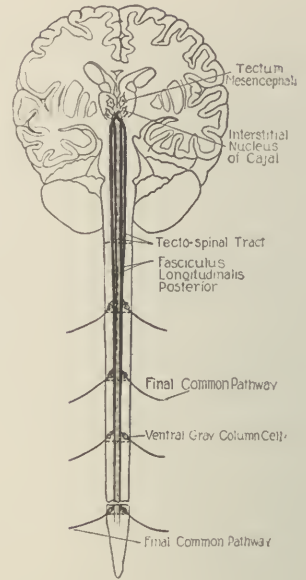
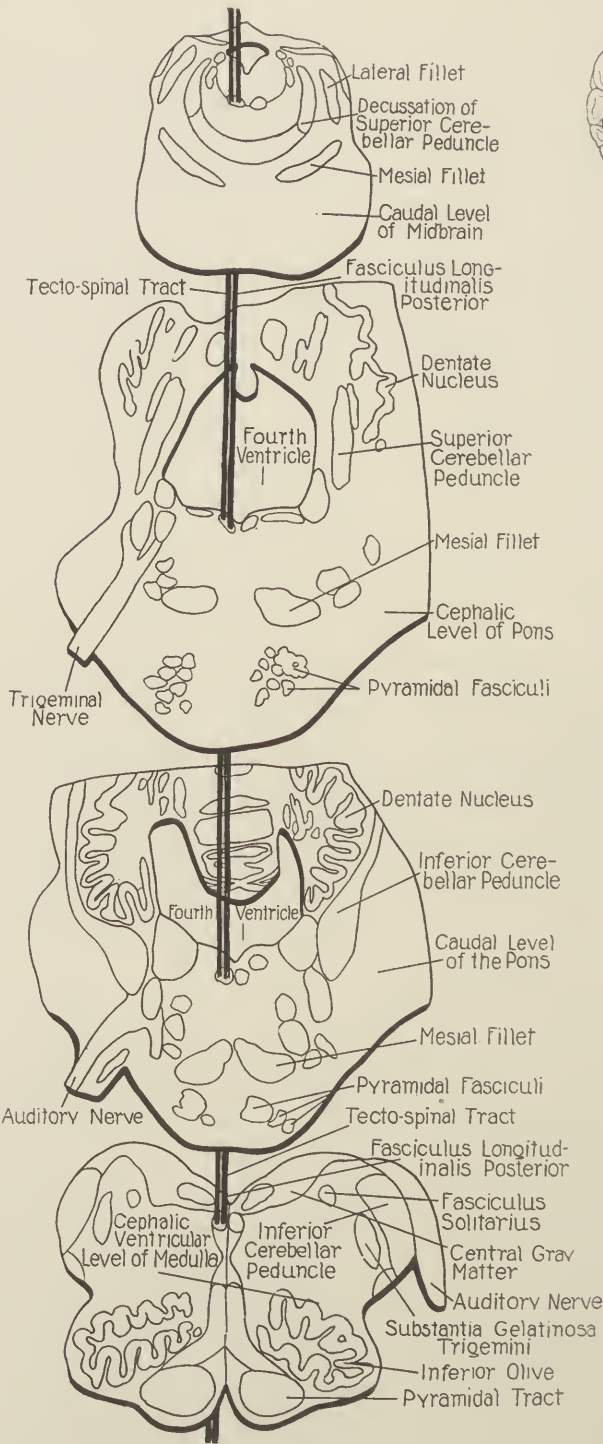


FIG. 285.—The fasciculus longitudinalis posterior and the tectospinal tracts. This represents the passage of these tracts through the pons. The tracts serve for the conduction of impulses from the tectum of the mid-brain and the interstitial nucleus of Cajal to the ventral gray column cells of the spinal cord and between the nuclei of the oculo-motor mechanism. They further serve as a part of the protective mechanism against excessive light impulses and other possible injuries. The fasciculus longitudinalis posterior contains both ascending and descending fibers.

jaw and tongue, while the anterior nares are distended to their full extent. This wide opening of the mouth in the effort of respiration resembles in many respects the respiratory activities carried on by the fish in its ordinary efforts to produce a circulation of water through the mouth and into the gills, each respiratory effort being attended by a marked depression of the lower jaw. This same action is observed during dyspnea, and is especially noticed in patients *in extremis* who, for a short time before death, show a distinct depressor movement of the lower jaw as the accompaniment of each respiratory movement. This depressor movement of the jaw continues even after all other respiratory action has ceased, a fact which seems to indicate that the mandibular movement observed prior to death is the persistence of one of the most primitive acts inherent in the respiratory mechanism.

THE PONS IN ITS RELATION TO PHONATION. The pons innervates muscle groups which serve to modify the production of voice sounds by movements of the jaws and lips. This modification of the voice is especially witnessed in the effects of mandibular and labial movements in speech, but it is also to be observed in all animals capable of phonation.

THE PONS IN ITS RELATION TO DEGLUTITION. The pons serves to innervate the muscles of mastication. But this is not an act of the masticatory muscles alone; it is dependent upon the combination of several nuclei situated in the pons, and also one in the medulla. The masticatory act is dependent upon the temporal and masseter muscles which press the lower jaw upward against the upper jaw, and thus approximate the upper and lower sets of teeth. In addition to this upward movement of the lower jaw, the pterygoid muscles, also supplied from the nucleus masticatorius, produce a grinding motion so that the food between the teeth may be subdivided and prepared for permeation by the secretion from the salivary glands. During this act of chewing, it is necessary that the food be held in the proper position between the teeth, otherwise it would escape under pressure applied by the masticatory muscles and move out either into the vestibule of the mouth or remain in contact with the tongue. For these reasons each movement producing an occlusion of the teeth is accompanied by a compression of the cheek which momentarily obliterates the vestibular space of the mouth and thus prevents food from slipping into this lateral pouch. Simultaneously, the tongue is firmly pressed against the hard palate and thus obliterates for the moment the mouth cavity. These two acts, therefore, synchronized with the occlusion of the teeth, prevent the food from finding any available space along either the outer or inner surface of the teeth. When the facial muscles of one side are paralyzed so that the vestibule is not properly obliterated, food escapes on each attempt at mastication from the paralyzed angle of the mouth. Also when the tongue is paralyzed, the food is not properly held between the teeth and mastication becomes difficult. The act of chewing, therefore, is a combination of movements causing the occlusion of the teeth and the obliteration of the vestibule and mouth cavity proper. To these acts should also be added one which produces a depression of the lower jaw in prepara-

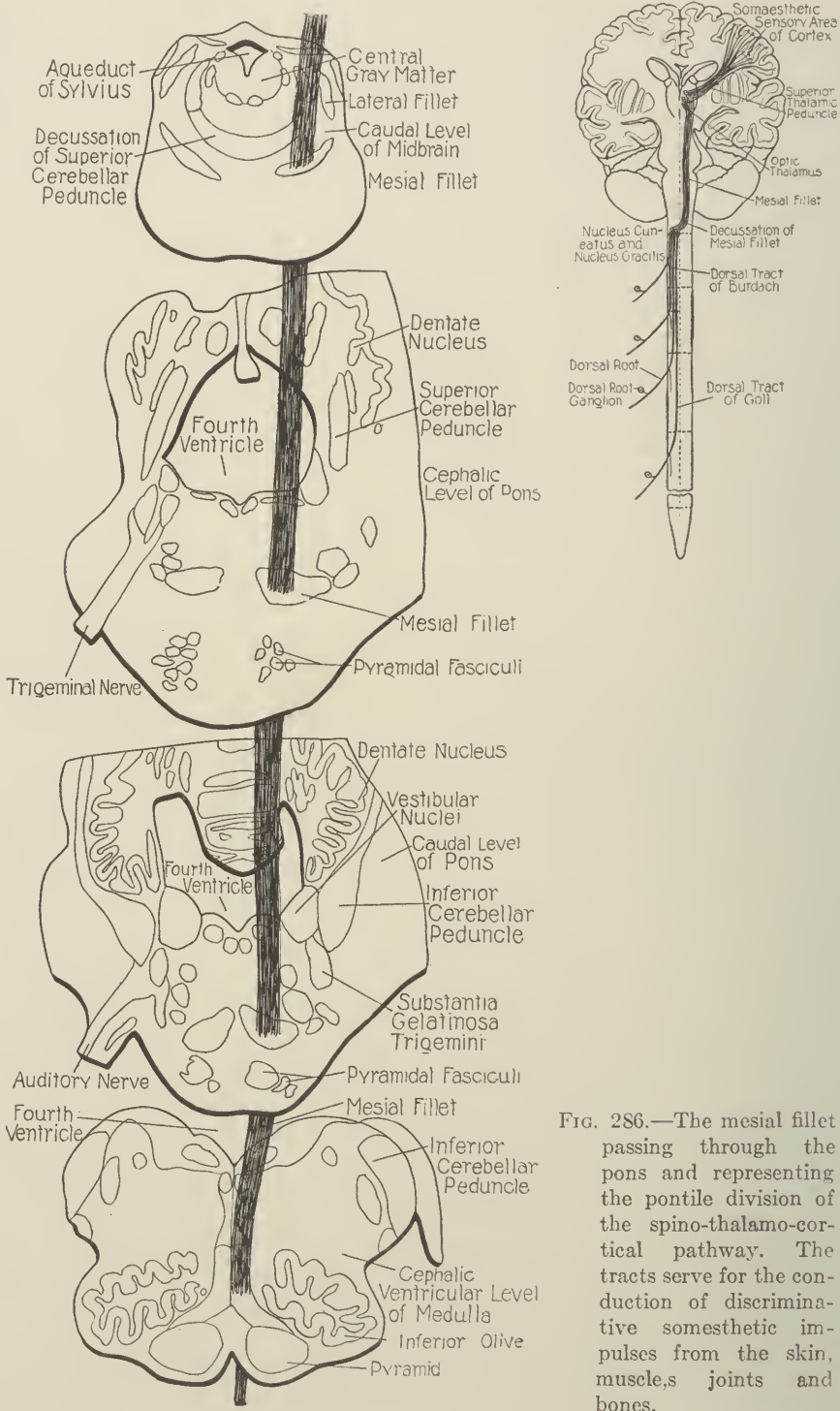


FIG. 286.—The mesial fillet passing through the pons and representing the pontile division of the spino-thalamo-cortical pathway. The tracts serve for the conduction of discriminative somesthetic impulses from the skin, muscles, joints and bones.

tion for each successive occlusion of the teeth under the action of the temporal and masseter muscles. This depression is performed mainly by the mylohyoid and the anterior belly of the digastric muscles.

The pons also innervates the muscles acting in the first phase of swallowing, which force the bolus of food, when properly prepared by mastication and permeated by salivary secretion, out of the mouth into the pharynx. This is accomplished by pressure of the tongue against the hard palate, by closure of the lips and by compression of the cheeks in such a way as to obliterate momentarily the vestibule of the mouth. The combination of these acts depends upon nerve impulses received from the pons Varolii.

THE PONS IN ITS RELATION TO SECRETION. Through the trigeminal nerve the pons innervates the sublingual and submaxillary glands from the *nucleus salivatorius superior*. It also innervates the sebaceous and sudoriferous glands of the face and fore part of the head and probably the lachrymal glands.

THE PONS IN ITS RELATION TO EYE MOVEMENTS AND HEARING. Through the nucleus of the sixth nerve, the pons innervates the external rectus muscle of the eye-ball. As already mentioned, this muscle serves as the pace-maker of all movements of lateral gaze. For this reason, the pons becomes one of the chief elements in the brain-stem controlling movements of the eyes. The greater number of oculogyric paralyses are attributable to lesions affecting this part of the brain. The pons is also important as affording relay stations in the secondary tracts of hearing. These relays are found in the nucleus of the superior olive and the nucleus trapezoideus.

The pontile nuclei, which constitute a large part of the massive structure of the pons, are recent acquisitions by the brain-stem. Their function is the relaying of impulses from the cerebral cortex to the cerebellum, thus bringing these two parts of the central nervous system into intimate relation for the purposes of synergic control in the regulation of skilled movements.

FUNCTIONS OF THE WHITE MATTER OF THE PONS

As is the case in the medulla oblongata, so with the pons, continuity in the conduction paths of the brain-stem is afforded by this division of the brain. Both ascending and descending tracts pass through the pons. Most of these have been encountered in the preceding segments; but in several instances new elements in the white matter have made their appearance.

Descending Tracts Traversing the Pons. The descending tracts which pass through the pons consist of those already described in the medulla oblongata.

The *pyramidal fibers* occupy a different position from those in any other part of the brain-stem, and have an arrangement which is characteristic of the pontile levels only. The pyramidal system, instead of being a solid, collected mass of fibers as in the medulla, consists of a number of fasciculi separated into bundles by the transverse fibers of the stratum complexum of the pons. The pyramidal fibers now occupy a position in the basis. The

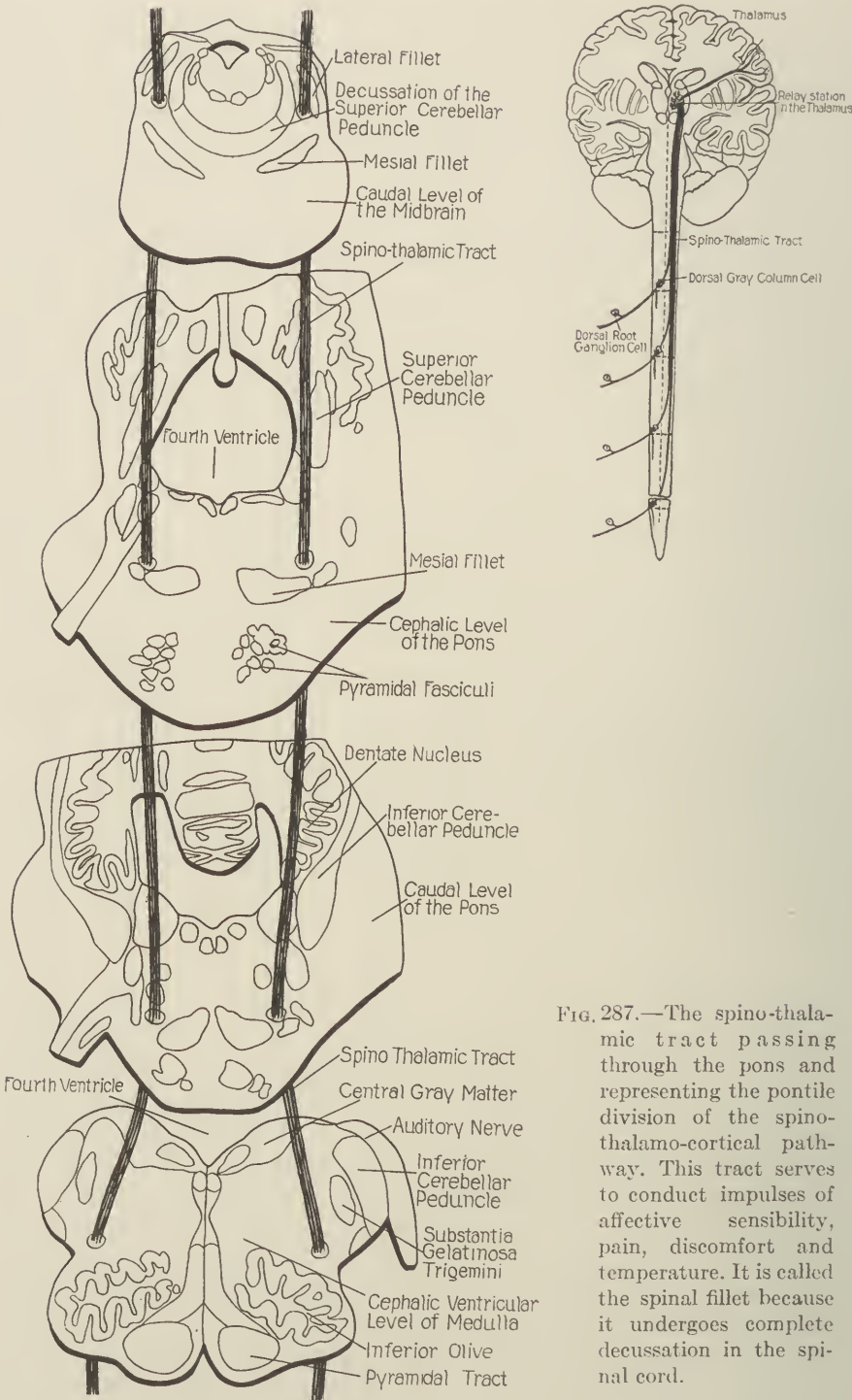


FIG. 287.—The spino-thalamic tract passing through the pons and representing the pontile division of the spino-thalamo-cortical pathway. This tract serves to conduct impulses of affective sensibility, pain, discomfort and temperature. It is called the spinal fillet because it undergoes complete decussation in the spinal cord.

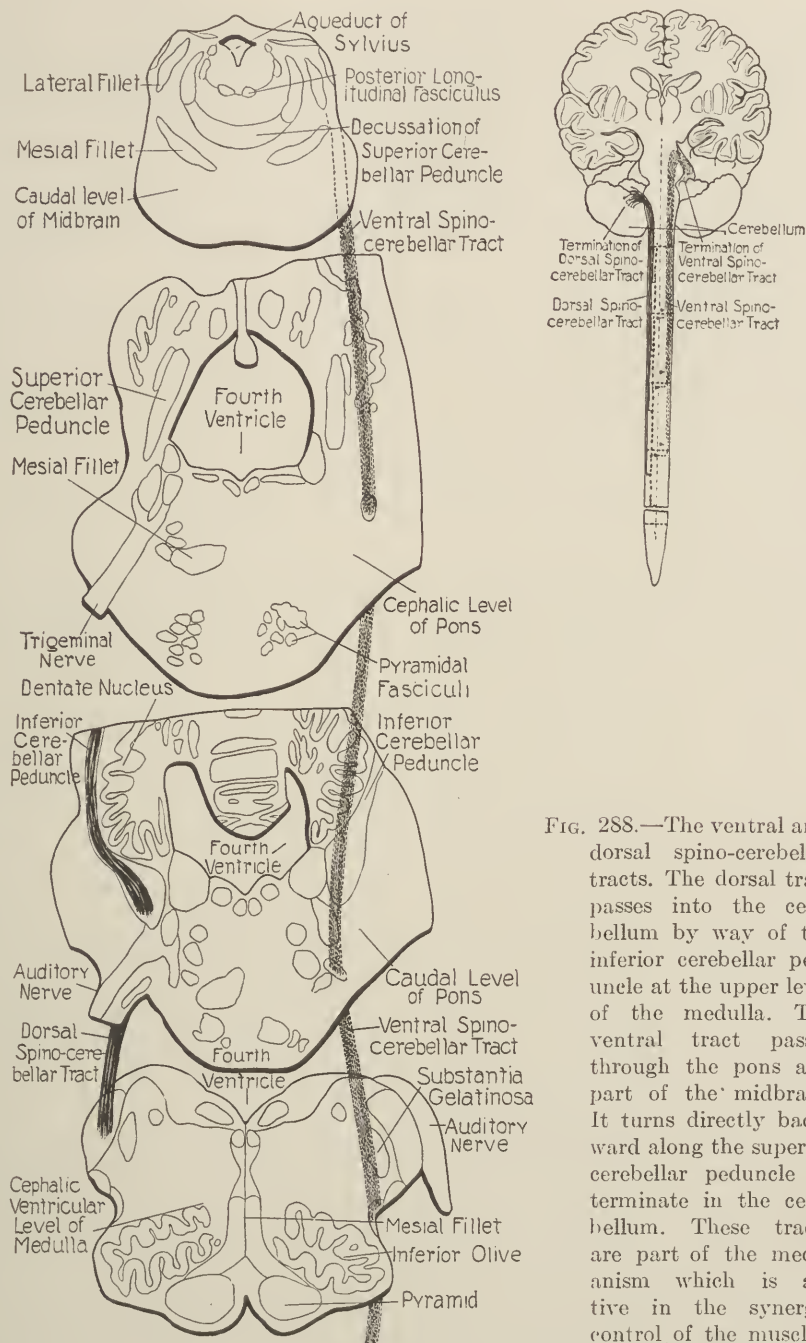


FIG. 288.—The ventral and dorsal spino-cerebellar tracts. The dorsal tract passes into the cerebellum by way of the inferior cerebellar peduncle at the upper level of the medulla. The ventral tract passes through the pons and part of the midbrain. It turns directly backward along the superior cerebellar peduncle to terminate in the cerebellum. These tracts are part of the mechanism which is active in the synergic control of the muscles.

ventral shift of these fibers is due to the interposition of the stratum profundum pontis between the pyramidal tract and the tegmentum. The actual boundary between the tegmentum and the pontile basis is the mesial fillet, whose ventral border is contiguous with the stratum profundum pontis.

The *tectospinal tract* is also found in the pons occupying its former close relation with the *fasciculus longitudinalis posterior*.

The *rubrospinal tract* lies in a position dorso-lateral to the superior olive.

The *central tegmental tract* occupies its usual position near the center of the reticular formation.

The *fasciculus dorsalis longitudinalis* of Schütz still holds its place in the central gray matter subjacent to the floor of the fourth ventricle.

The *reticular formation*, while not so rich in gray matter, consists of the large formatio reticularis alba, in which are many descending fibers intimately connected with the splanchnic functions.

The Ascending Tracts Traversing the Pons. The ascending tracts in the pons likewise show but slight addition to their representation as seen in the medulla.

The *mesial fillet* is present but somewhat altered in its relation and position. It now extends transversely across the neuraxis forming the boundary between the tegmentum and pontile basis. This shift into a ventral position is consequent upon the removal of the pyramidal system out of relation with the tegmentum into the basis.

The *spino-thalamic tract* lies ventral to the rubrospinal tract and mesial to the ventral spino-cerebellar tract. The Deitero-spinal tracts have already consummated their connection with the vestibular nuclei and consequently do not appear in the pontile levels. A few fibers of the ventral Deitero-spinal tract may occasionally be observed in the caudal levels of the pons.

The *fasciculus longitudinalis posterior* occupies its usual position subjacent to the floor of the fourth ventricle, mesial to the nucleus of the sixth nerve and ventral to the nucleus incertus and nucleus funiculi teretis.

One tract, the *lateral fillet*, a secondary connection in the cochlear pathway, has made its appearance in the pons. It is formed by fibers which have undergone decussation in the trapezoid crossing, or have reached the secondary stage in their course after decussating either in the floor of the fourth ventricle or immediately below it. This tract occupies a position lateral and adjacent to the mesial fillet. It serves to convey auditory impulses to the brain.

At this level, three distinct fillet systems are discernible; First, the *spinal fillet*, consisting of a sensory pathway which has undergone decussation in the spinal cord and ascends into the medulla and through the pons as the spino-thalamic tract. Second, the *bulbar* or *mesial fillet*, which has undergone decussation in the medulla; after crossing it has ascended through the remainder of the medulla and pons as the mesial fillet. Third, the *pontile* or *lateral fillet*, which after decussation in the pons becomes a collected bundle ascending in a position lateral to the mesial fillet. All of these afferent tracts serve as parts of sensory pathways; the spino-thalamic tract for the

purposes of pain-temperature conduction; the mesial fillet for the purpose of the conduction of critical somesthetic sensibility, and the lateral fillet for the purposes of auditory conduction.

Decussations in the Pons. Two major decussations take place in the pons. The largest and most important of these is the pontile decussation consummated through the transverse fibers of the pons and serving to establish a crossed connection between the cerebral cortex and the lateral lobe of the cerebellum. The fibers of this decussation are found in three layers, the stratum superficiale, the stratum profundum and the stratum complexum. Each fiber in the decussation is relayed in the pontile nuclei before it crosses the midline to enter into the formation of the opposite middle cerebellar peduncle. The purpose of this decussation and the communication which it establishes are in the interest of synergic control in skilled movements.

The second decussation of the pons is the cochlear or trapezoid decussation which takes place in the tegmental portion of the hindbrain in intimate relation with the mesial fillet. This decussation affords a crossing in the auditory path which, after the fibers have decussated, is constituted as the lateral fillet, a secondary auditory tract on the way toward the cerebral hemispheres.

PRINCIPAL SYNDROMES OF THE PONS VAROLII

As in the medulla, lesions in the pons resulting from disease or injury seldom confine themselves to either the gray or the white matter, but involve some part of both of these elements simultaneously. Only the more frequent and illustrative symptom-complexes arising as the result of involvement of the pons will be considered in the following descriptions:

Syndrome of the Head and Eye-Turning Contingent of the Aberrant Pyramidal System. **HISTORY.** A child, four years old, had complained of frequent headaches for five weeks. He was listless and fretful most of this time. There was a slight, irregular rise in temperature during the latter part of his illness. His parents noticed that both eyes were drawn toward the right and that he seemed unable to move his eyes toward the left. His head was also turned so that the chin pointed toward the right. The von Pirquet test was positive. The temperature rose gradually for several days, and after a bronchopneumonia lasting five days, he died.

EXAMINATION. At the onset of his oculomotor symptoms, examination showed the following:

The *somatic motor component*, with the exception of the oculomotor paralysis, was normal in all particulars. Idiodynamic, reflex, tonic, volitional, synergic and associated automatic control were normal. There was a paralysis of the left external and right internal recti muscles of the eyes, giving rise to a paralysis of left lateral gaze (levogyric ocular paralysis) which produced a right conjugate deviation. The intrinsic muscles of the eyes were normal.

The *somatic sensory component* was normal.

The *splanchnic motor component* showed a paralysis of the right sterno-cleido-mastoid and trapezius muscles which resulted in a dextrocephalogyric paralysis, so that the head was turned in such a way that the chin pointed toward the right under the action of the unopposed levocephalogyric muscles. In other respects the splanchnic motor control was normal.

The *splanchnic sensory control* was normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. Evidence of the focus of the lesion shows that the pathological process was situated in such a

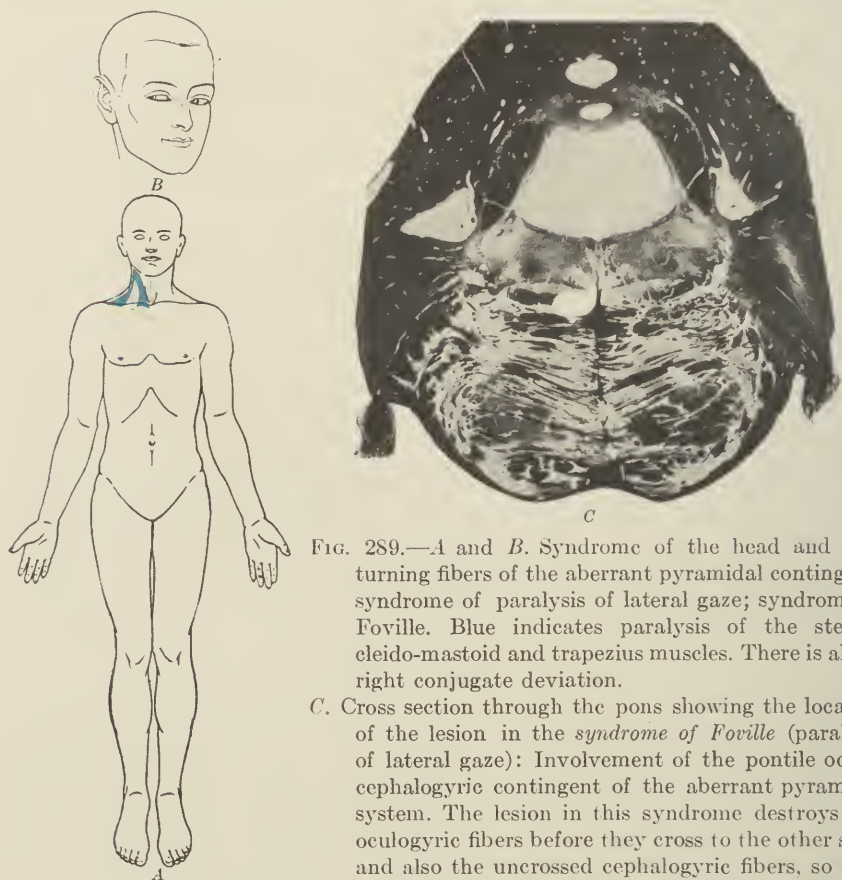


FIG. 289.—A and B. Syndrome of the head and eye-turning fibers of the aberrant pyramidal contingent: syndrome of paralysis of lateral gaze; syndrome of Foville. Blue indicates paralysis of the sterno-cleido-mastoid and trapezius muscles. There is also a right conjugate deviation.

C. Cross section through the pons showing the location of the lesion in the *syndrome of Foville* (paralysis of lateral gaze): Involvement of the pontile oculo-cephalogyric contingent of the aberrant pyramidal system. The lesion in this syndrome destroys the oculogyric fibers before they cross to the other side, and also the uncrossed cephalogyric fibers, so that a single lesion paralyzes the levogyric oculomotor apparatus and the right cephalogyric muscles.

position that it involved the oculogyric and cephalogyric fibers of the right side. Such a focus exists near the cephalic limit of the pons. Here the pontile aberrant pyramidal contingent is still isolated between the fillet and pyramidal system.

The evidence of circumscription of the lesion is afforded by the absence of all other somatic and splanchnic motor and sensory disturbances.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is a tuberculoma

of the pons on the right side. The actual lesion discovered was about the size of a small pea.

NOMENCLATURE. This is the *syndrome of paralysis of lateral gaze*; it is also called the *syndrome of Foville*.

SUMMARY. The essential clinical features of the syndrome of Foville are:

1. Paralysis of lateral gaze contralateral to the lesion producing ipsilateral conjugate deviation of the eyes, affecting the oculogyric fibers above their level of crossing.

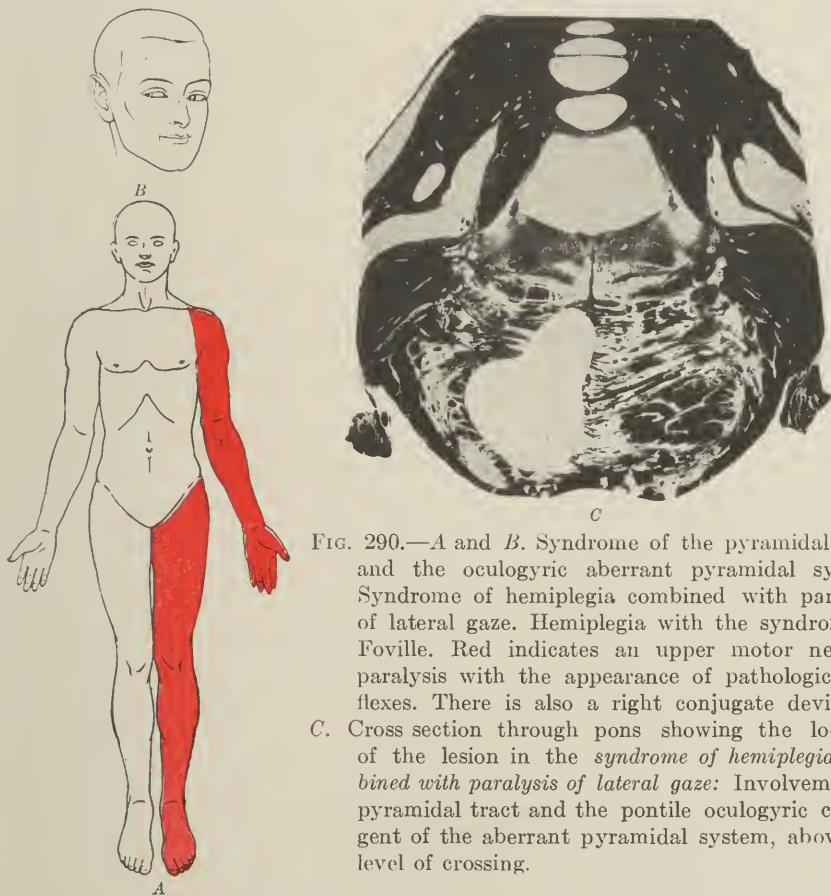


FIG. 290.—A and B. Syndrome of the pyramidal tract and the oculogyric aberrant pyramidal system. Syndrome of hemiplegia combined with paralysis of lateral gaze. Hemiplegia with the syndrome of Foville. Red indicates an upper motor neurone paralysis with the appearance of pathological reflexes. There is also a right conjugate deviation.
C. Cross section through pons showing the location of the lesion in the *syndrome of hemiplegia combined with paralysis of lateral gaze*: Involvement of pyramidal tract and the pontile oculogyric contingent of the aberrant pyramidal system, above the level of crossing.

2. Paralysis of lateral rotation of the head contralateral to the lesion producing contralateral deviation of the head.

3. The absence of all other sensory and motor symptoms.

Syndrome of the Pyramid and the Oculogyric Aberrant Pyramidal System.

HISTORY. A man, sixty-seven years of age who had suffered from the effects of prolonged high blood pressure and nephritis, had an apoplectic seizure. Upon recovering from the acute stage it was found that he had

a left hemiplegia and a paralysis of left lateral gaze with right conjugate deviation of the eyes. Several months after his initial seizure he had a second apoplectic attack in which he died.

EXAMINATION. Upon examination after his first seizure, he presented the following:

The *somatic motor component* showed idiodynamic control in all movements of the body normal. The deep reflexes of the left side were all more active than those of the right side. There was a Babinski and ankle clonus on the left but none on the right. The muscle tone of the left side was increased as compared with that on the right. Volitional control was lost in the left arm and leg and in these parts abnormal associated movements were observed. Equilibratory and synergic control could not be judged on the left side because of the paralysis, but elsewhere were normal. There was a paralysis of left lateral gaze involving both eyes and the head. The patient could not look to the left, and the eyes were held in right conjugate deviation. The head was turned so that the chin pointed to the right.

The *somatic sensory component* was normal.

The *splanchnic motor component* was normal.

The *splanchnic sensory component* was normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion was a vascular accident, in all probability a hemorrhage, because of the history of prolonged high blood pressure, the nephritis and the two apoplectic seizures.

Evidence of the focus of the lesion resulting from the first apoplectic attack is given in the simultaneous involvement of the right pyramidal system and the aberrant pyramidal fibers serving for oculogyric and cephalogyric movements. Such a region is to be found in the pons near its cephalic extremity, where the aberrant fibers which have left their pyramidal association are passing obliquely backward toward the mesial fillet. In this region they lie in the stratum profundum between the fillet and the pyramidal tracts.

The evidence of circumscription of the lesion is given by the absence of all other sensory and motor symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this case is hemorrhage in the pons near its cephalic extremity upon the right side.

NOMENCLATURE. This is the *syndrome of hemiplegia combined with paralysis of lateral gaze*. It is also known as *hemiplegia with the syndrome of Foville*.

SUMMARY. The essential clinical features of hemiplegia with the syndrome of Foville are:

1. Hemiplegia contralateral to the lesion.
2. Paralysis of lateral gaze contralateral to the lesion.
3. The absence of all other sensory and motor symptoms.

Syndrome of the Mesial Fillet, the Pyramidal and the Oculogyric Aberrant Pyramidal Systems. HISTORY. A married woman, forty-one years of age, who had had four miscarriages and one still-born child, suddenly and with-

out premonitory symptoms developed a partial hemiplegia of the right side. She was unable to look to the right, and the eyes were turned in such a way that they were held turned toward the extreme left. In the course of several weeks she lost tactile sensibility in the right arm and leg and the right side of the body up to the interauricular line. Muscle, joint and vibratory sensibility were also defective in these areas. The Wassermann reaction in the blood and spinal fluid was positive. After a course of intensive antiluetic treatment she made a complete recovery.

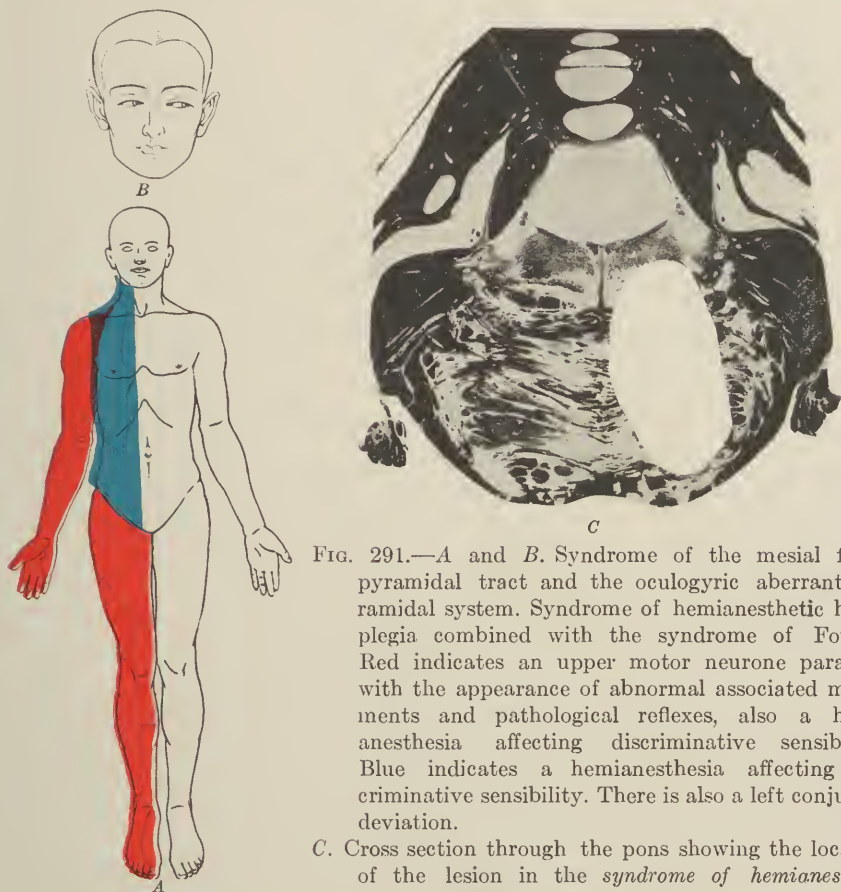


FIG. 291.—A and B. Syndrome of the mesial fillet, pyramidal tract and the oculogyric aberrant pyramidal system. Syndrome of hemianesthetic hemiplegia combined with the syndrome of Foville. Red indicates an upper motor neurone paralysis with the appearance of abnormal associated movements and pathological reflexes, also a hemianesthesia affecting discriminative sensibility. Blue indicates a hemianesthesia affecting discriminative sensibility. There is also a left conjugate deviation.

C. Cross section through the pons showing the location of the lesion in the *syndrome of hemianesthetic hemiplegia combined with a paralysis of lateral gaze*: Involvement of pyramidal tract, mesial fillet, and oculogyric contingent of aberrant pyramidal system above the level of crossing.

EXAMINATION. When examined shortly after the appearance of the right hemiplegia, she manifested the following:

The *somatic motor component* showed that the idiodynamic control of the entire musculature of the body was normal. All the reflexes on the right side were more active than those on the left. There was a right-sided Babinski and ankle clonus. The right abdominal reflexes were absent. The tone

of the muscles in the right arm and leg was increased over that upon the left side. Volitional control in the right arm and leg was much diminished. Equilibratory and synergic control on the right side were difficult to estimate because of the paralysis. On the left side coordination was normal. Abnormal associated movements were present in the right arm and leg. With the exception of the third and sixth nerves, the cranial nerves were normal. There was a marked paralysis of the right external rectus and left internal rectus. This defect gave rise to a paralysis of right lateral gaze which resulted in a left conjugate deviation, the eyes being drawn over by the unopposed antagonists to the side opposite the paralysis.

The *somatic sensory component* showed a hemianesthesia of the discriminative type on the right side of the body exclusive of the head and face, ventral to the interauricular line. All other qualities of sensibility were normal. The left side of the body showed no sensory defect.

The *splanchnic motor component* showed that with the exception of the paralysis of the cephalogyric muscles causing a paralysis of dextrogyric head movements, there were no disturbances in this component.

The *splanchnic sensory component* was normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion was due to syphilis, as shown by the Wassermann test and the ready response to antiluetic treatment.

Evidence of the focus of the lesion is given by the simultaneous involvement of the pyramid, the fillet and the aberrant oculogyric and cephalogyric pyramidal systems. Such an involvement might be determined by a lesion in the cephalic portion of the pons affecting the basis and tegmentum.

Evidence of circumscription of the lesion is furnished by the absence of all other motor or sensory symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this case is a *vascular type of neurosyphilis* involving the cephalic portion of the pons on the left side.

NOMENCLATURE. This is the *syndrome of hemianesthetic hemiplegia combined with the syndrome of Foville*.

SUMMARY. The essential clinical features of the syndrome of hemianesthetic hemiplegia with the syndrome of Foville are:

1. Upper motor hemiplegia contralateral to the lesion.
2. Hemianesthesia of the discriminative type contralateral to the lesion.
3. Oculogyric paralysis contralateral to the lesion, producing conjugate deviation ipsilateral with the lesion.
4. Cephalogyric paralysis contralateral to the lesion, producing cephalogyric deviation ipsilateral with the lesion.
5. Absence of all other motor and sensory symptoms.

The Syndrome of the Pyramidal System and the Emergent Fibers of the Abducens Nerve. HISTORY. A man, thirty-eight years of age, who was employed as an inspector of gas mains, became unconscious while making an examination in a poorly ventilated conduit into which much illuminating gas had escaped. After being carried into the air he re-

mained unconscious and stuporous for several days. When he regained sufficient consciousness to make examination possible it was found that he was suffering from a left hemiplegia and a paralysis of the right external rectus which gave him an internal strabismus of the right eye with diplopia (double vision). The subsequent course of events in this patient's case was of considerable interest, as he remained in the hospital for fifteen weeks, and was an invalid unable to return to work for a year and a half. At the end of this time he had made a fair recovery and was assigned to

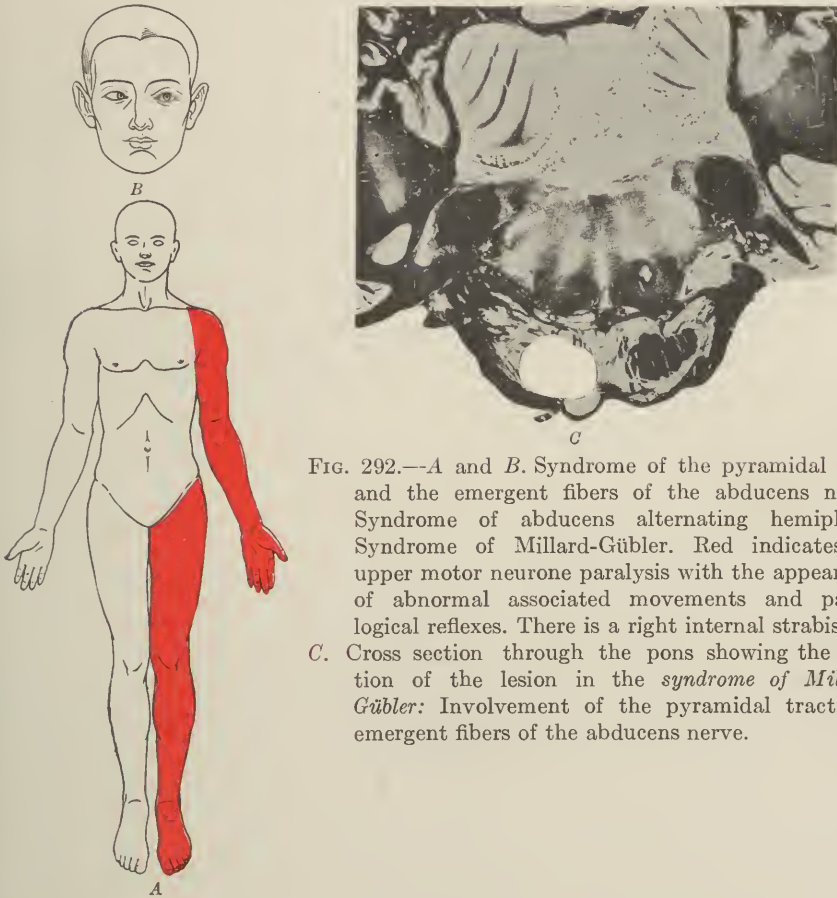


FIG. 292.—A and B. Syndrome of the pyramidal tract and the emergent fibers of the abducens nerve. Syndrome of abducens alternating hemiplegia. Syndrome of Millard-Gübler. Red indicates an upper motor neurone paralysis with the appearance of abnormal associated movements and pathological reflexes. There is a right internal strabismus. C. Cross section through the pons showing the position of the lesion in the *syndrome of Millard-Gübler*: Involvement of the pyramidal tract and emergent fibers of the abducens nerve.

work which, however, did not call upon him for further exposure to illuminating gas.

EXAMINATION. Examination was made when he regained consciousness after his exposure to the gas.

The *somatic motor component* showed that there was normal idiodynamic control of all the musculature of the body. The deep reflexes on the left side were all more active than the right; there was a left ankle clonus and a left Babinski. There was an absence of the abdominal reflexes on the left. The muscle tone of the left side was distinctly increased as compared with that

of the right side. The volitional control of the left side of the body was defective so that the patient had very little voluntary movement in the left arm and leg. There were definite abnormal associated movements in the left arm and leg and none on the right side. Synergic and equilibratory control could not be judged in the left arm and leg because of the existing paralysis, although they were normal in all other parts of the body. The right external rectus muscle was paralyzed, indicating an involvement of the right abducens nerve. All of the other cranial nerves were normal.

The *somatic sensory component* showed no defect.

The *splanchnic motor component* was normal.

The *splanchnic sensory component* was normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of this lesion was a thrombosis resulting from exposure to illuminating gas. Such a lesion in some region of the brain is not infrequent as the result of this type of toxemia.

Evidence of the focus of the lesion is afforded by the simultaneous involvement of the pyramidal fibers and the sixth nerve. Such a region exists in the caudal portion of the pons in the level at which the sixth nerve is about to make its escape from the brain-stem. A small lesion here would involve both the emergent fibers of the sixth nerve and the pyramidal tract, thus giving rise to a paralysis of the external rectus muscle of one side and a hemiplegia of the opposite side.

Evidence of circumscription of the lesion was afforded by the absence of all other motor and sensory symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this case is thrombosis of the more caudal levels of the pons upon the right side.

NOMENCLATURE. This is the *syndrome of abducens alternating hemiplegia*. It is also known as the *syndrome of Millard-Gübler*.

VARIATIONS. The syndrome of Millard-Gübler is subject to several variations. The patient in this case showed some of them while in the hospital. Ten days after his admission, he developed a complete peripheral facial paralysis of the right side. This was due to the extension of the lesion to the emergent fibers of the seventh nerve. At this time it was also observed that he had a considerable degree of deafness, more marked upon the right side than the left; this was due to the involvement of the trapezoid body. The facial paralysis was accompanied by a partial loss of the sense of taste on the anterior two-thirds of the tongue.

In some cases the lesion may extend dorsally and involve the fibers of the mesial fillet as well as the aberrant pyramidal oculogyric fibers, in which case this type of alternating hemiplegia would be complicated by an anesthesia of the opposite side, combined with the syndrome of Foville.

SUMMARY. The essential clinical features of the syndrome of abducens alternating hemiplegia (syndrome of Millard-Gübler) are:

1. Hemiplegia contralateral to the lesion.
2. Involvement of the abducens nerve causing ipsilateral paralysis of the external rectus with internal strabismus and diplopia.

3. The absence of all other motor and sensory symptoms.

Syndrome of the Pyramid, Fillet, Inferior Cerebellar Peduncle and Posterior Longitudinal Fasciculus. HISTORY. A young woman, twenty-five years of age, who had been suffering from malignant endocarditis, suddenly became paralyzed on the left side with a complete loss of sensation over the left half of the body. Both eyes were turned to the right due to a paralysis of left lateral gaze. This paralysis was accompanied by considerable dissociation of the eye

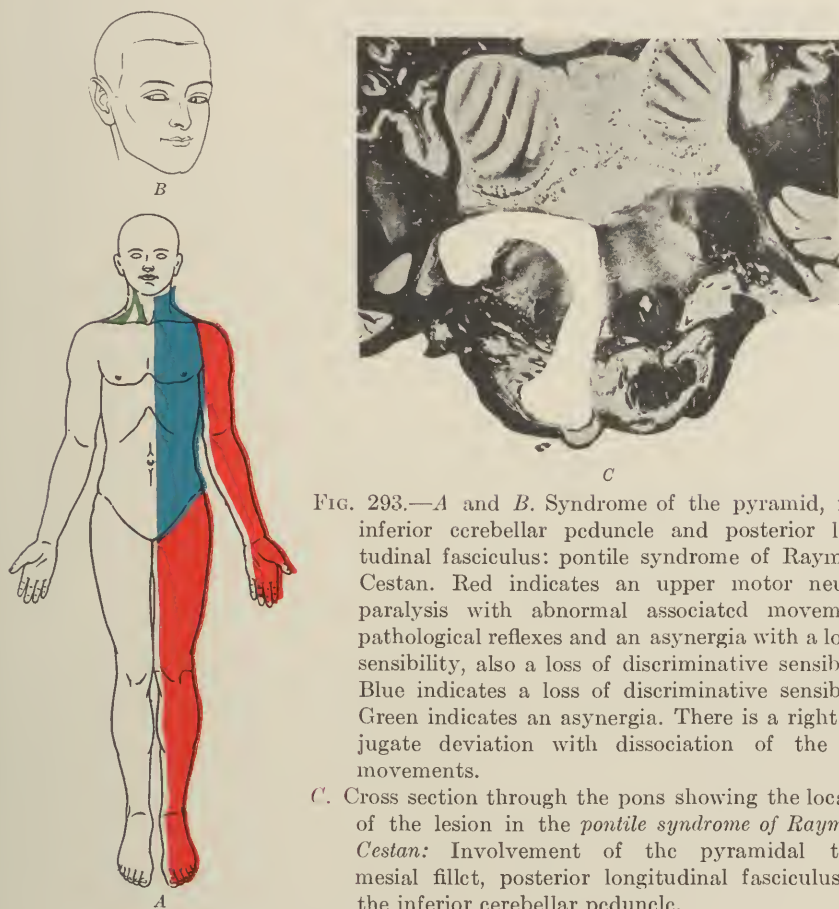


FIG. 293.—A and B. Syndrome of the pyramid, fillet, inferior cerebellar peduncle and posterior longitudinal fasciculus: pontile syndrome of Raymond-Cestan. Red indicates an upper motor neurone paralysis with abnormal associated movements, pathological reflexes and an asynergia with a loss of sensibility, also a loss of discriminative sensibility. Blue indicates a loss of discriminative sensibility. Green indicates an asynergia. There is a right conjugate deviation with dissociation of the eye-movements.

C. Cross section through the pons showing the location of the lesion in the *pontile syndrome of Raymond-Cestan*: Involvement of the pyramidal tract, mesial fillet, posterior longitudinal fasciculus and the inferior cerebellar peduncle.

movements in attempts to look to the left and also as the eyes moved to the side opposite the paralysis. The patient survived the development of these brain symptoms for several weeks, but finally succumbed suddenly as the result of pulmonary embolism.

EXAMINATION. Examination at the time when she developed symptoms referable to the nervous system, revealed the following:

The *somatic motor component* showed that the idiodynamic control was normal in all parts of the body. The deep reflexes on the left side were much

more active than on the right side. There was a doubtful Babinski on the left and no ankle clonus on the right or left. The upper lateral abdominal reflex was gone upon the left, the left lower lateral abdominal reflex was present, as were the abdominal reflexes on the right side. There was a slight increase in the tone of the muscles of the left arm and leg, otherwise muscle tone was normal in the body. Volitional control was defective in the left arm and leg, although the patient was able to make some movements with these parts. In attempting to move the right arm and leg, there was a distinct defect in synergic control. This was due to an *asynergia*. Equilibratory control could not be tested. Abnormal associated movements were found at times in the left arm and leg but were not constant. There was a distinct paralysis of left lateral gaze as a result of which the eyes tended to be held in right conjugate deviation, although the patient was able to make some attempts to look to the left. At such times the eyes were no longer conjugated, but showed a distinct dissociation of their movements. This gave the patient a transitory diplopia. All of the other cranial nerves were normal.

The *somatic sensory component* showed a marked defect in discriminative sensibility upon the left half of the body, including the neck and head up to the interauricular line. Other qualities of sensibility were preserved in the affected areas, and in the rest of the body no sensory disturbances were detected.

The *splanchnic motor component* showed some loss of cephalogyric movement to the left, although the paralysis was not complete.

The *splanchnic sensory component* was normal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was an embolus consequent upon an endocarditis. This embolus affected one of the large median branches of the basilar artery.

Evidence of the focus of the lesion is furnished by the simultaneous involvement of the pyramid, the fillet, the inferior cerebellar peduncle and the posterior longitudinal fasciculus. The most likely position for such a lesion is in the extreme caudal limit of the pons. The lesion is of necessity a large one, involving an extensive area in the tegmentum of the right side and extending sufficiently forward in the pons to involve the pyramidal system.

Evidence of circumscription of the lesion is afforded by the absence of other motor and sensory symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this case is an *embolus of the basilar artery affecting the caudal portion of the pons Varolii*.

NOMENCLATURE. This is the *pontile syndrome of Raymond-Cestan*.

SUMMARY. The essential clinical features of the pontile syndrome of Raymond-Cestan are:

1. Hemiplegia contralateral to the lesion.
2. Hemianesthesia (discriminative) contralateral to the lesion.
3. Contralateral oculogyric paralysis with dissociation of the eye movements giving rise to a transitory diplopia.
4. Hemiasynergia ipsilateral with the lesion.
5. The absence of all other motor and sensory symptoms.

CHAPTER XXIII

THE CEREBELLUM

A GENERAL VIEW OF ITS EVOLUTIONAL SIGNIFICANCE

A Suprasegmental Portion of the Nervous System. The cerebellum, or "little brain," is the expanded dorsal portion of the metencephalon. In mammals it is next in point of size to the cerebral hemispheres, from which it is separated by a membranous or bony plate, the *tentorium cerebelli*. In the lower vertebrates the cerebellum, although variable in size, is constant in its general characters. Because of its position above the segmented parts of the neuraxis, it is called *suprasegmental*.

This designation recognizes not only the cerebellar relation to the rest of the central nervous system, but is meant even more to imply a sublimation in this organ of a certain control of special functions over which the cerebellum stands supreme. There are two other suprasegmental structures in the brain besides the cerebellum, the *tectum of the midbrain* and the *cerebral hemispheres*. All of these suprasegmental organs, however, have the same general significance; they serve the purposes of some special functions for which the segmented portion of the neuraxis in itself does not provide; and they are, by their morphological nature, capable of great expansion where the demands of adaptation require the most complex correlations of nerve impulses. Contrasted with the suprasegmental parts of the brain, the segmental portion of the neuraxis presents a decided inflexibility in its morphological character, and is susceptible of but a small degree of expansion. It was originally endowed with and persistently retains the control of the definitely fixed and fundamental organic reactions. It is the foundation without which a superstructure would be impossible. The ground plan of the segmented portion of the central nervous system in vertebrates is constant. The decisive differences in the form of the brain occur in its suprasegmental parts, and as these latter vary in their degree of development, so animals differ in their range of adaptability to their environment.

The cerebellum, like the other suprasegmental organs of the brain, differs from the segmented portions of the neuraxis in certain essential particulars:

1. The cerebellar gray matter forms a cortex surrounding the white matter. This is a reversal of the relation of the gray to the white matter in the segmented portion of the nervous system. Such a position of the cell-containing substance greatly enhances the opportunity for expansion, since the cortex is not hampered, as is the case in the spinal cord and medulla, by a heavy investment of white matter.

2. The cerebellar connection, by means of peripheral nerve fibers, with receptors and effectors of the body, is much less direct than that of the

segmented parts. This undoubtedly provides for less immediate reflex action, but also makes possible a greater degree of correlation of nerve impulses in each cerebellar reaction.

The Phyletic Constancy of the Cerebellum. The cerebellum is an organ of great antiquity. Even among invertebrates, certain arthropods (crabs), according to Bethe, have a structure in the central nervous system whose functions appear to be analogous to those of the cerebellum. Among vertebrates it is a constant element of the brain, although subject to pronounced variations. The variability of its development depends upon a definite rule. Those animals which are capable of limited and simple movements possess a small and simple cerebellum, whereas animals having



FIG. 294.—Diagrammatic representation of the cerebellum in the vertebrate series, dorsal view. Darkened area.

Petromyzon (lamprey) above. *Scyllium canicula* (dog-fish) below.

a wide range of motor activity possess a highly developed cerebellum. The organ appears in its simplest form in cyclostomes and amphibia, animals whose activities are relatively the most sluggish.

A brief review of the appearance of the cerebellum in the several classes of vertebrates serves to emphasize the importance of this rule.

The Cerebellum in the Different Classes of Vertebrates. In *cyclostomes*, the cerebellum is but little developed; it appears as two slight dorso-lateral evaginations of the metencephalon connected across the fourth ventricle by a central arched portion. The most conspicuous parts are the dorso-lateral evaginations. These are in direct connection with the somatic sensory tracts and receive some general and special cutaneous nerve fibers. It is probable that the cerebellum is connected with the gustatory sense in

these forms. Histologically, there is evidence of beginning differentiation into the types of cells characteristic of the cerebellum, for certain large cellular elements are present, both in the dorso-lateral evaginations and in the central arch. Many medium sized nerve-cells are also present and tend to take up positions in a deeper stratum. These cellular elements are doubtless the forerunners of the Purkinje cells and the cells of the granular layer. Axones from some of the large cells follow a course similar to those seen in secondary cutaneous tracts and decussate in the mesencephalon. Johnston believes they may represent fibers in the superior cerebellar peduncle of the higher vertebrates which arise in the dentate nucleus and reach the red nucleus in the midbrain. If such is the case, these large cells themselves



FIG. 295.—Diagrammatic representation of the cerebellum in the vertebrate series, dorsal view. Darkened area.

Salmo salar (salmon) above. *Rana esculenta* (frog) below.

are the prototypes of the cellular elements later found in the dentate nucleus.

This simple form of cerebellum corresponds with the sluggish motor habits of the cyclostomes.

In *selachians* (the sharks and rays), the cerebellum shows a marked advance in development; it consists of a large arch in the reduplicated roof-plate of the metencephalon, having many evaginations into which recesses from the cavity of the fourth ventricle extend. Its greater volume as compared with the cyclostomes is consequent upon the greatly increased size and complexity of its somatic sensory portion. Histologically, the organ shows much further specialization than in the cyclostomes. There are many more granular cells, which form a dense, compact *granular layer* whose axones project into a more superficial zone forming the *molecular layer*. The larger cells have many of the histological characters of the typical *Purkinje cells* and are arranged as a row on the border between the mole-

ular and granular layers. The cerebellum receives root fibers from the somatic sensory nerves, and is in connection with secondary tracts from somatic sensory centers.

These connections indicate that the organ acts both as a primary receiving center of somatic sensory impulses from the muscles, skin, ear and eye, and is an area for the correlation of impulses necessary to somatic sensibility. In the more lateral portions of the cerebellar evaginations are situated secondary splanchnic sensory nuclei related to the gustatory sense. Axones from these nuclei pass inward to form a decussation in the anterior medullary

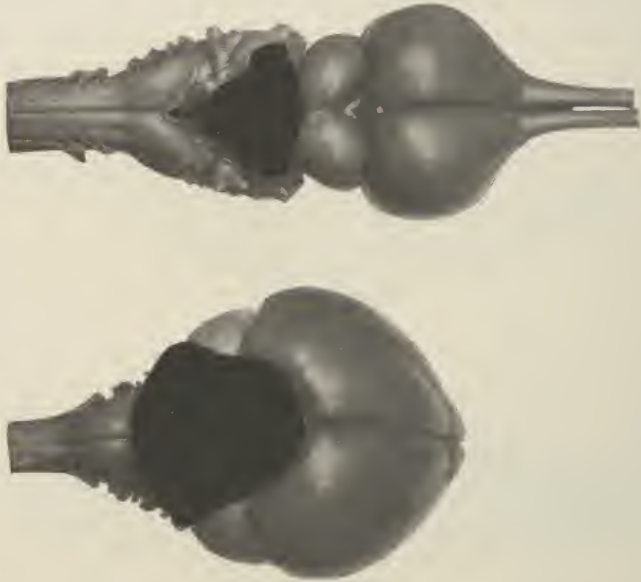


FIG. 296.—Diagrammatic representation of the cerebellum in the vertebrate series, dorsal view. Darkened area.

Alligator Mississippiensis (alligator) above. Columba (pigeon) below.

velum in close relation with the decussation of the trochlear nerves. This is the *decussatio veli*.

The selachians are free swimming fish possessed of great speed and power of movement. Their motor activities carry them to great depths and enable them to swim at all levels for long distances.

In *teleosts* and *ganoids*, the cerebellum is not essentially different from that of selachians. The somatic sensory portion in itself is not so large, but it has a richer connection with other somatic sensory centers, and thus becomes more important in the correlation of sensory impulses received from the muscles, skin, ear and eye. The splanchnic sensory nuclei are much larger than in the selachians, due to the greater development of the gustatory organs in the bony fish and ganoids. The central arch of the cerebellum is larger than the lateral evaginations.

In their motor activities, the bony fish and ganoids are in many ways similar to the selachians.

In *amphibia*, due to the generally sluggish habits of these animals, the cerebellum is small, and next to the cyclostomes, the simplest of all vertebrates. Its reduction in size as compared with selachians and the bony fish is due to the small number of special cutaneous and gustatory organs. The lateral evaginations which contain the somatic sensory elements, form a simple arch over the ventricle, but present no reduplication. The granular, molecular and Purkinje layers, however, are well marked. The more active amphibia, such as the frog, have much larger lateral lobes, due to an increase in the secondary tracts connected with muscular, cutaneous, vestibular and optic receptors. The cerebellum in such forms is more highly organized as a correlating mechanism.

In *reptiles*, with the exception of the crocodile, alligator and turtle, the cerebellum is small. In these more active forms it is of relatively large size.

In *birds* an important advance is witnessed in the great development of the central arch or keystone of the cerebellum, which becomes much convoluted to form the *vermis cerebelli*. This part of the cerebellum does not, properly speaking, appear in the lower classes of the vertebrate series. The lateral cerebellar evaginations are present in much reduced form as the *flocculus* and *paraflocculus*. Evidence is wanting at present to war-

rant a complete statement regarding the evolution of the cerebellum in the higher vertebrates, although the conspicuous development of the vermis in birds seems to be indisputably connected with the necessities of flying. The cerebellum in ratite birds, such as the ostrich and cassowary, has a smaller vermis than in the bird of passage or in those birds whose locomotion depends mainly upon the wings.

In *mammals*, all of the elements necessary to cerebellar development in the lower vertebrates are present, including the central arch and the two lateral evaginations. The central arch becomes somewhat more complex even than in birds; but it is the expansion of the lateral evaginations in forming the lateral cerebellar lobes which differentiates the mammalian cerebellum from all others. The *hemispheres* of the cerebellum are the last



FIG. 297.—Diagrammatic representation of the cerebellum in the vertebrate series, dorsal view. Darkened area.

Lepus cuniculus (rabbit) above. *Canis familiaris* (dog) below.

parts phylogenetically to make their appearance, although it is incorrect to maintain that the vermis appears before the lateral lobes. The earliest portions of the cerebellum are the two lateral evaginations, which become connected across the ventricle by the central arch. The primitive derivatives of the lateral evaginations are the flocculus and parafocculus. Subsequently a more cephalic area of the lateral evaginations gives rise to the hemispheres. The essential changes which appear in the formation of the mammalian cerebellum are:

1. The increase in size and complexity of the central arch in forming the vermis.
2. The development of the lateral evaginations cephalad of the flocculus and parafocculus to form the cerebellar hemispheres.
3. The persistence of the flocculus and parafocculus in rudimentary conditions, these structures in the more primitive forms being the chief representatives of the lateral evaginations.
4. The submergence of portions of the lateral evaginations to form the dentate nucleus and other medullary nuclei in the cerebellum.

The vermis, hemispheres, rudimentary flocculus and parafocculus are the essential features of the mammalian cerebellum. These anatomical divisions of the organ vary in their development in different orders of mammals, according to the needs of the animal.

The cerebellum in the lowest mammals, the *monotremes*, has a large vermis but small and simple hemispheres. In *marsupials*, those forms requiring much synergic control, such as the kangaroo, have large hemispheres and vermis, while the opossum, whose motor activities are limited, has a simple cerebellum.

The cerebellum is relatively simple in *rodents*, whose locomotion carries them near the ground and whose general motor capacity is not extensive. In contrast to the rodent, the *carnivores*, because of a locomotion which carries the body at a distance from the ground, have a more complex cerebellum. The great power of these animals, either in springing or climbing, makes still further demands upon the cerebellum.

The *ungulates* have an especially well developed cerebellum, particularly those whose extremities are long, such as the camel and giraffe. In the *proboscidea*, the cerebellum attains an exceptional size. This is the case in elephants whose great body weight, being sustained and carried at some distance from the ground, requires an extensive synergic control to maintain equilibrium.

Certain of the *aquatic carnivores*, for example the seals, have a large and highly developed cerebellum by means of which they are enabled to execute the complex acts necessary to swimming and the performance of the swift correlated movements of the head and trunk by which they defend themselves and procure their food.

But by far the most highly developed cerebellum is seen in the *primates*. The *anthropoid apes*, representing as they do the transition from the quadruped to the biped, possess a complex cerebellum which, in the main, is

the morphological response to the needs of coordination in arboreal life, but which also foreshadows the inception of the process that has freed the upper extremities from responsibility in locomotion. This process has resulted in the establishment of a motor organ which eventually has come to have the widest range of motor activity, the human hand and arm. The relative size and complexity of the cerebellum among the different forms of primates are of interest. Those living a strictly arboreal life show a pronounced development in the vermis and the tentorial surfaces of the hemispheres.



FIG. 298.—Cerebellum of mountain-goat (*Oreamnos montanus*).



FIG. 299.—Cerebellum of dog (*Canis familiaris*).



FIG. 300.—Cerebellum of sloth bear (*Melursus labiatus*).



FIG. 301.—Cerebellum of ape (*Macacus rhesus*).

Those forms in which the biped tendency has made further advance, with the gradual freeing of the upper extremities from direct participation in locomotion, such as the *gorilla*, *chimpanzee* and *orang-outang*, have a greater degree of development in the occipital surfaces of the hemispheres. This morphological fact is of much significance, since it is in full accord with the now generally accepted conceptions of cerebellar localizations. Considering the requirements of such a mobile organ as the human hand and arm, and the demands of synergic control in the performance of biped locomotion, it is not surprising to find the most highly developed cerebellum in man.

Generalized Pattern of the Cerebellum in Mammals. Descriptions of the cerebellum have caused much confusion, because they have been based upon the conditions of the most complex of all forms, man. Elliot Smith and Bolk have demonstrated that such divisions as have been employed for the human cerebellum will not meet the requirements in the different orders of mammals. A simplified scheme for the divisions of this organ has been devised by Elliot Smith and supplemented in a later work by Bolk. Smith's studies were based upon the cerebellum in the edentata; those of Bolk were made upon the cerebellum of lemur albifrons. Both investigators recognize an *anterior* and a *posterior cerebellar lobe* separated from each other by a large fissure which appears early in development, the *fissura prima*. The posterior lobe is further subdivided by a second fissure

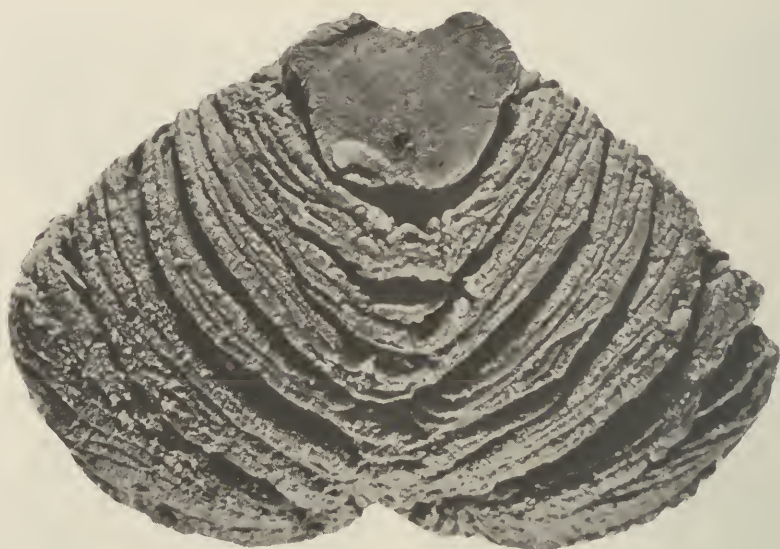


FIG. 302.—Cerebellum of chimpanzee (*Troglodytes niger*).

appearing later in development, the *fissura secunda*. As growth proceeds, the anterior lobe becomes subdivided by other secondary fissures, *i.e.*, (1) the *fissura preculminata* and (2) the *fissura lingulis*.

These fissures determine three subdivisions in the anterior lobe, the most cephalic of which is the *lingula*; the middle, the *pars preculminata*; and the most caudal, the *pars culminis*. The posterior lobe shows much more subdivision. In it are recognized a median portion corresponding in position to the *vermis*, which is divided into four parts by three parallel fissures: (1) The *fissura suprapyramidalis*; (2) the *fissura secunda*, and (3) the *fissura prenodularis*. These fissures divide the median portion into the *pars suprapyramidalis*, the *pyramid*, the *uvula* and the *nodula*. The lateral expansion connected with this portion of the *vermis* is divisible into two parts, the *pars lateralis* and the *pars flocculi*. The *pars lateralis* is the lateral expansion of all that part of the *vermis* cephalad of the *fissura secunda*, while the *pars*

flocculi is the lateral expansion of the nodule and uvula. The pars lateralis is subdivided into certain smaller areas by the appearance of three radiating fissures which converge upon the vermis. These fissures are the *fissura postlunata*, the *fissura postpteroidea* and the *fissura parapyramidalis*.

The area cephalad of the fissura postlunata is the area lunata. Caudal to this in regular succession are the area *pteroidea*, the area *postpteroidea* and the area *parapyramidalis*.

The pars flocculi is divided by a fissure which extends inward from the lateral extremity about one-third of the distance toward the nodule; this is the fissura floccularis, which separates the paraflocculus from the flocculus. The fissura parafloccularis intervenes between the pars lateralis and pars flocculi.



FIG. 303.—Schematization of the fundamental arrangement of the parts of the mammalian cerebellum spread out in one plane, according to Elliot Smith, as a result of his original work on the cerebellum of the edentata.

This pattern, according to Elliot Smith, may be applied to the analysis of the cerebellum of all vertebrates with the possible exception of the monotremes.

Bolk, as the result of a study of the cerebellum in a large comparative series, still further advanced the ideas put forward by Elliot Smith. He concluded that the several parts recognizable in the mammalian cerebellum have definite functional significance, and represent areas of central control over definite motor performances in the body. According to Bolk, the cerebellum is divided into an anterior and posterior lobe by the sulcus primarius which corresponds to the fissura prima of Smith. The anterior lobe is divided by a series of three fissures into four lobules which Bolk numbers 1, 2, 3, and 4. A small and shallow fissure parallel to the sulcus primarius delimits the *lobulus simplex*, which extends from the vermis out upon the lateral expansions of the hemispheres. The major portion of the posterior lobe, however, that which lies caudal to the lobulus simplex, is divided into a median lobule and two lateral lobules. The median lobule constitutes the vermis and is separated from the lateral lobules by the two sulci paramediani, one of which lies on either side of the vermis. The vermis itself is divided into four lobules, respectively indicated as C-2 and C-1,

B and *A*. The fissura secunda passes between *C*-1 and *B*. The lateral lobules are divided into two main portions, the *lobulus ansiformis* and the *formatio vermicularis*. These lobules are separated by a deep incisure, the largest fissure in the cerebellum, the fissura parafloccula. The lobulus anciformis is divided by a transverse fissure, the *sulcus intercruralis*, into Crus I and Crus II. Where the lobulus anciformis and the formatio vermicularis come into relation with the posterior median lobule, there is a portion of the cerebellum which Bolk defines as the *lobus paramedianus*. Bolk explains the striking variations of the cerebellum on the grounds that form is dependent upon function, and there must, therefore, be some direct functional relationship between these variations in the cerebellum and the control of the muscular system whose tonic, sthenic and static activities are dependent upon this organ. He concludes that all of the muscles of the body may be divided into two groups: those which act bilaterally together, such as the trunk muscles,

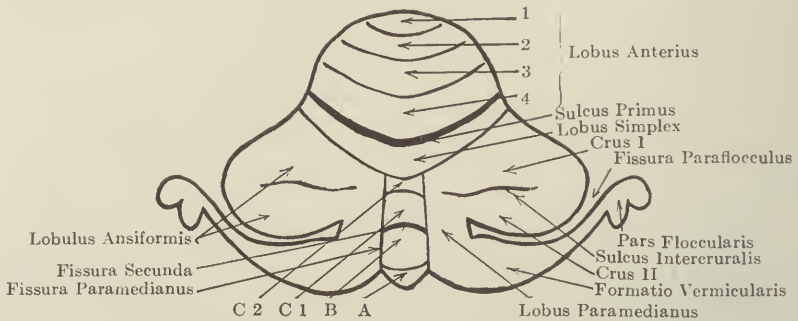


FIG. 304.—Schematization of the fundamental arrangement of the parts of the mammalian cerebellum spread out in one plane, according to Bolk, who selected for his type the cerebellum of *lemur albifrons*.

and those which, although bilaterally present, have a certain independence in their activity, like the muscles of the arms and legs. The muscle groups which show this independence of action are unilaterally synergic, while those which depend upon a simultaneous coordination are bilaterally synergic. To the latter group belong the muscles which produce movements of the head, of the eyes, of the mouth and jaws, of the tongue, pharynx and larynx, and of the trunk, in addition to certain movements of the upper and lower extremities which require bilateral innervation and act together as in locomotion. Upon this hypothesis Bolk bases his localization in the cerebellum of control for the two major groups of muscles. The cerebellar cortex is composed in mammals of a number of coordinating centers, some of which are paired for unilateral synergic control, while some are unpaired for bilateral synergic control.

The *lobulus anterior cerebelli* contains the coordinating centers for the muscles which are active in movements of the head. The most anterior lobule is for the eyes; the second lobule, for the tongue; the third, for the muscles of mastication, and the fourth, for the muscles of expression and of the larynx and pharynx. The *lobulus simplex* contains the unpaired synergic

centers for the muscles of the neck. In the upper portion of the lobulus medianus posterior are the unpaired centers for movements of the left and right extremities. The lobuli ansiformes and paramediani contain paired centers for the extremities, the arrangement of the centers in each case being homolateral, Crus I corresponding to the arm of the same side and Crus II to the leg of the same side. The remainder of the cerebellum contains coordinating centers for the trunk and the tail region, the formatio vermicularis particularly having control of the tail.

This localization in the cerebellum by Bolk on the grounds of comparative anatomy was subsequently confirmed by André Thomas and Durupt and by Van Rijnberk by experiments upon animals.

Uniformity of the Internal Structure of the Cerebellum. Throughout the vertebrate series, the cerebellum presents a striking uniformity in its internal structure, and is so different from other parts of the central nervous

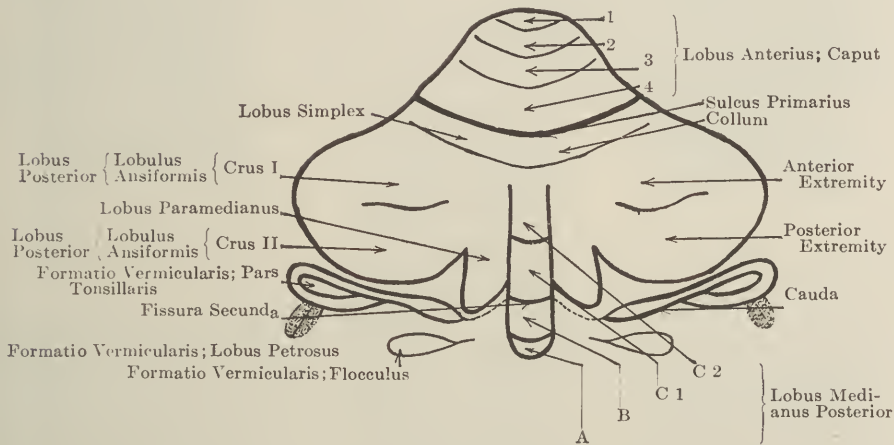


FIG. 305.—Schematization of the parts of the mammalian cerebellum spread out in one plane. (Van Rijnberk.)

system as to suggest a definite specialization of function which has been present almost from the first in vertebrates. This uniformity in the internal structure appears in the arrangement of the nerve cells and the fibers participating in the formation of the cerebellum. The innermost layer of nerve cells consists of medium sized elements which are placed closely together and give the area a granular appearance. This is the *granular layer*. The dendrites of the cells of this layer extend toward the surface and spread out to form a second layer of about the same depth consisting mainly of end branches of axones, among which are scattered a few nerve cells. This is the *molecular layer*. On the border between the granular and molecular layers, there develops a row of large cellular elements placed in regular order along this boundary line, the *cells of Purkinje*. Running along this border-line, in relation with the cells of Purkinje, is a thin stratum of nerve fibers, while internal to the granular layer is a stratum of fibers

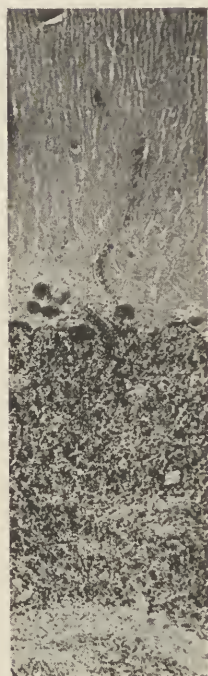


FIG. 306.—Cortex cerebelli in shark (*Squalus acanthias*), showing three strata of cells.

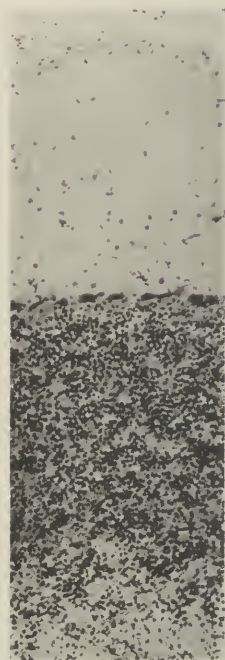


FIG. 307.—Cortex cerebelli in turtle (*Chelonia mydes*), showing three strata of cells.

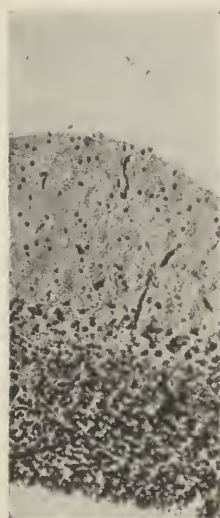


FIG. 308.—Cortex cerebelli in frog (*Rana sylvatica*), showing three strata of cells.

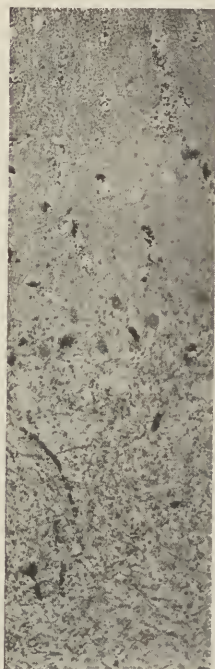


FIG. 309.—Cortex cerebelli in alligator (*Alligator Mississippiensis*), showing three strata of cells.

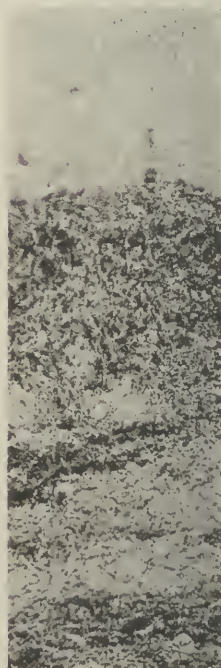


FIG. 310.—Cortex cerebelli in codfish (*Gadus morrhua*), showing three strata of cells.



FIG. 311.—Cortex cerebelli in pigeon (*Columba*), showing three strata of cells.



FIG. 312.—Cortex cerebelli in dog (*Canis familiaris*), showing three strata of cells.



FIG. 313.—Cortex cerebelli in rabbit (*Lepus*), showing three strata of cells.



FIG. 314.—Cortex cerebelli in chimpanzee (*Troglodytes niger*), showing three strata of cells.

of somewhat greater thickness. These are known respectively as the *external* and *internal medullary strata*. On the outer surface of the molecular layer is a thin stratum of nerve fibers called the *marginal zone* or *zonal layer*.

In summary, the internal structure of the cerebellum presents:

1. The outermost zonal layer, made up of the end branches of axones from cells in the granular layer.
2. The molecular layer, containing the axones of the granular cells and the dendrites of the Purkinje cells, among which are scattered a few nerve-cells.
3. The Purkinje layer, consisting of a single row of large Purkinje cells.
4. The external medullary stratum.
5. The granular layer, consisting mainly of granule cells.
6. The internal medullary stratum.

This type of internal structure is seen in all vertebrates with the exception of the cyclostomes, in which the differentiation into layers, although indistinct, is far enough advanced to foreshadow the ultimate cerebellar stratification. In the lower vertebrates, a recess or series of recesses connected with the fourth ventricle extends into the cerebellar evagination. In mammals, the diverticula from the ventricle are not present, because this space is now occupied by a branching mass of white matter which constitutes the *arbor vitæ*.

In addition to these histological elements which are constant in the vertebrate series, several other more diffuse masses of gray matter appear in relation with the medullary substance. One of these bodies of gray matter consists of a bilateral collection of nerve cells, the *nucleus globosus*, one situated upon either side in the vermis near its cephalic extremity. These two nuclei are well developed in mammals and in birds. They are present, though less well defined, in reptiles and amphibia. There is some evidence of their presence in certain groups of fish. In birds and reptiles, there is a small collection of nerve cells lateral to the nucleus globosus, constituting the *nucleus lateralis*, which is probably identical with a highly developed nucleus in mammals, the *nucleus dentatus*. In reptiles, birds and mammals, two distinct nuclei appear in the roof of the fourth ventricle mesial to the nucleus globosus. These are the *nuclei tecti* or *fastigii*, while somewhat ventro-mesial to the nucleus dentatus in mammals is a large collection of nerve-cells, the *nucleus emboliformis*. Collectively, these nuclei occupying positions in the white matter are spoken of as the *medullary nuclei* of the cerebellum.

Even within the narrow limits of the primates, these medullary nuclei vary much in their distinctness and prominence. It is only in man, gorilla, chimpanzee, orang-outang and gibbon, that the nucleus dentatus has the typical convoluted appearance which resembles the inferior olive of the medulla, a fact which has led to the term, *oliva cerebelli*. In the lower apes, the convoluted appearance of the cerebellar olive is scarcely discernible.

Primitive Connections of the Cerebellum. The cerebellum receives root fibers from several somatic sensory nerves, notably the seventh, which, in the fish, establish a primary connection with lateral line organs of the

supra-orbital, infra-orbital and hyomandibular rows. In many of the fish there is also a large vagus connection. In all of the lower vertebrates, including birds, the cerebellum is connected with secondary somatic sensory tracts of the somesthetic, optic and auditory centers. There is a primary splanchnic sensory connection in the cerebellum serving the gustatory sense, and likewise a secondary pathway through the cerebellum for this type of sensibility. All of the more exact connections of the cerebellum among vertebrates are difficult to enumerate at the present time. The vertebrates, exclusive of birds and mammals, possess two tracts which connect the diencephalon with the cerebellum. These are particularly well developed in teleosts and selachians, although less well defined in amphibians and reptiles. They are the *tractus diencephalo-cerebellares*. In fish, amphibia and reptiles, the brachium conjunctivum anterius contains three main tracts:

1. The *tractus tegmento-cerebellaris*, which arises in the ganglion at the caudal end of the tegmental portion of the diencephalon and is a crossed connection having its decussation in the cephalic extremity of the midbrain.
2. The *tractus mesencephalo-cerebellaris*, which is also a crossed connection with its decussation in the superior medullary velum in close relation with the decussation of the trochlear nerve.
3. The *tractus tecto-cerebellaris*, which is likewise a crossed connection arising in the tectum of the mesencephalon and having its decussation in the velum forming part of the *decussatio veli*.

In all vertebrates, the brachium posterius, known in mammals as the inferior cerebellar peduncle, contains fibers from the following sources:

1. *Tractus spino-cerebellaris*, both a direct and crossed connection.
2. *Fibræ arcuatæ anteriores and posteriores*.
3. *Tractus vestibulo-cerebellaris* and, in selachians and teleosts, a *tractus trigemino-vago-cerebellaris*.

In mammals, the posterior brachium is augmented by a large contingent from the inferior olive constituting the *tractus olivo-cerebellaris*.

From these connections it is evident that the cerebellum, even from its earliest history, has borne an extensive relation to all the different forms of sensibility, including somesthetic, optic, auditory and gustatory. It is also provided with an ample association system, which permits the organ to serve as a center for correlation. This sensory correlation has had, from the inception of cerebellar development, a definite purpose, as shown by the internal structure of the cerebellum, which has maintained a constant morphological character. The function of the organ must, therefore, have been constant, and its correlation of sensory impulses derived from so many different sources must have had a common aim. All of the facts seem to indicate that this correlation was in the interest of regulating motion by the addition to motor performance of that essential element termed synergic control.

The Connections of the Cerebellum in Mammals. With the exception of the gustatory connection, which no longer plays a part in the sensory contributions entering into cerebellar correlation, the sensory tracts to the

cerebellum in mammals indicate that the essential nature of the organ has remained unchanged through the later stages of evolution. Three peduncles with certain accessory connections serve to connect the mammalian cerebellum with the rest of the central axis. These are the *superior cerebellar peduncle*, corresponding to the *brachium conjunctivum anterius*; the *inferior cerebellar peduncle* or *restiform body*, corresponding to the *brachium posterius*, and the *middle cerebellar peduncle*, a mammalian acquisition not present in the lower vertebrates. According to the observations of Van



FIG. 315.—Cortex cerebelli in man, showing three strata of cells.

Gehuchten, the following functional groups of fibers participate in the cerebellar connections:

1. Through the inferior cerebellar peduncle, which contains:

- (a) The dorsal spino-cerebellar tract from the muscles, joints and tendons.

- (b) A secondary connection with the columns of Goll and Burdach through the anterior and posterior arcuate fibers establishing direct and crossed connections, also from the muscles, joints and tendons; and possibly from the skin.

- (c) The olivo-cerebellar tract, direct and crossed, connecting both

inferior olives with the cerebellum, coordinating the movements of the head with those of the eyes.

2. Through the juxtarestiform body, which contains:

(a) A Deitero-cerebellar tract connecting the nucleus of Deiters with the nucleus tecti of the cerebellum for equilibratory control.

(b) A secondary connection between the substantia gelatinosa, (representing the trigeminal nerve) and the vermis of the cerebellum.

3. Through the superior cerebellar peduncle, which contains the

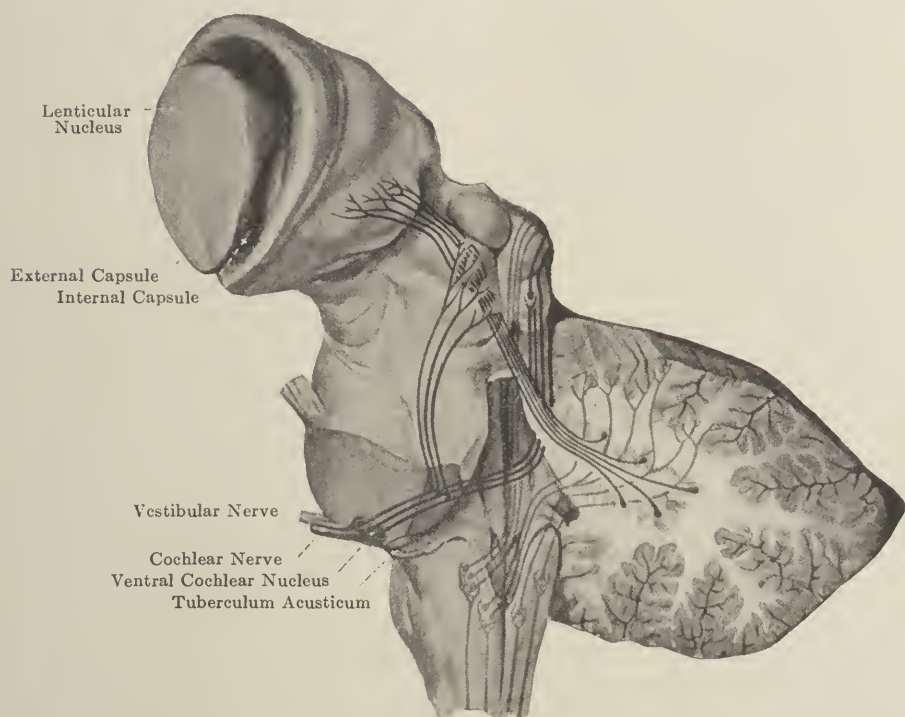


FIG. 316.—Course of some of the greater conduction paths in the brain. On the left side the cerebellum has been completely removed, as has the cerebrum, with the exception of the large ganglia; on the right side the posterior superior part of the cerebral hemisphere has been removed by a vertical (not exactly frontal) and a horizontal section. The brain is viewed from the left and from behind. (*Held.*)

dentato-mesencephalic and the dentato-diencephalic fibers, the former ending in the red nucleus after a complete decussation in the mid-brain, and the latter extending to nuclei of the thalamus. It is possible that some fibers extend from the red nucleus to the dentate nucleus; but the superior cerebellar peduncle serves as the chief pathway for impulses leaving the cerebellum.

4. Through the middle cerebellar peduncle, which contains fibers serving as a connection between the frontal, occipital, parietal and temporal lobes of the cerebral hemispheres and the lateral lobes of the cerebellum. This establishes a completely crossed connection through the pontile decussation.

5. Through the fibers of the ventral spino-cerebellar tract, which enter the vermis of the cerebellum after traversing the lateral aspect of the superior cerebellar peduncle.

It is evident that the cerebellar connections in mammals indicate the same functional capacity as in the lower vertebrates. The fibers in the inferior cerebellar peduncle represent an extensive connection between the muscles,

bones and joints and, perhaps, to some degree the cutaneous surfaces of the body. The juxtarestiform body is indicative of a connection between the semi-circular canals, utricle and saccule of the internal ear on the one hand and the cerebellum on the other, still retaining the ancient relation which in many of the lower vertebrates is much more extensive, because it includes the organs of the lateral line. The connections through the middle cerebellar peduncle provide opportunity for more efficient sensory associations than in the primitive forms, since they mediate sensory impulses arising in the occipital, temporal, parietal and frontal lobes of the cerebral hemispheres, and serve respectively for the ultimate elaboration of visual, auditory, somesthetic and kinesthetic impressions.

The superior cerebellar peduncles represent amplified pathways by means of which fibers leave the cerebellum for the spinal cord and brain-stem. This is a more voluminous connection, because the correlation which occurs in the cerebellum of mammals, being more extensive and complex, needs a larger pathway for distribution.

The Evolutional Significance of the Cerebellum. From the early stages of vertebrate history, the cerebellum has served as an organ of association

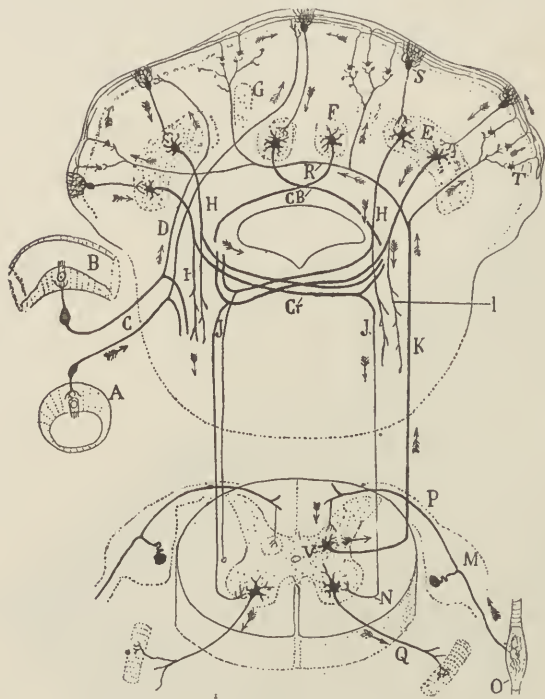


FIG. 317.—Diagram of the afferent and efferent tracts of the cerebellum. The arrows indicate the direction of the impulse. (Cajal.)

A, B—Vestibular cells whose axones probably send their ascending bifurcating branches to join with the Purkinje cells. C—Fibers of the vestibular nerve. CB—Crossed cerebello-bulbar tract. Cr—Decussation of the superior cerebellar peduncle. D—Ascending branch of the vestibular axone, probably joining with the Purkinje cells. E—Dentate nucleus giving rise to the superior cerebellar peduncle. F—Ganglion of the roof, at the point where the crossed cerebello-bulbar tract commences. G—Nucleus globosus and emboliformis. H—Superior cerebellar peduncle. I—Direct descending branch of superior cerebellar peduncle. J—Crossed descending branch of the peduncle. K—Ascending sensory tract originating in Clarke's column and probably joining with the granule cells by the intermediation of the mossy fibers. M—Spinal ganglion. N—Termination of the crossed descending branch of the superior cerebellar peduncle in the anterior horn cell of the cord. O—Muscle tendon organ of Kühne. P—Posterior root partly joined to Clarke's column. Q—Anterior or motor root. R—Spino-cerebellar sensory tract. S—Purkinje cell. T—Mossy fibers. V—Clarke's column giving rise to the ascending cerebellar sensory tract.

for sensory impulses which are correlated and distributed in order to maintain the muscles of the body in a state of synergy. The advantages accruing to this process from the combination of vestibular, auditory, somesthetic and optic impressions cannot be called in question.

The most primitive vertebrate motion depends upon the harmonious innervation of the axial musculature, whose action must be coordinated from body-segment to body-segment, and synchronized upon the two sides of the body. Such animals as depend upon swimming movements for their locomotion, and in which swimming movements represent the maximum motor achievement, require a bilateral synergic control. The mechanism best calculated to supply this control would consist of unpaired interdependent collections of coordinating cells. Such an organ is the cerebellum in all of the fish. In some lower vertebrates the necessity for this bilateral synergic control is much less than in others, as for example the cyclostomes, which are animals solely dependent upon a vermicular movement for all their motor activity. A similar vermicular movement is sufficient in the reptiles to carry them over the surface of the ground. This is also true of the more sluggish of the amphibia whose movements are of a similar

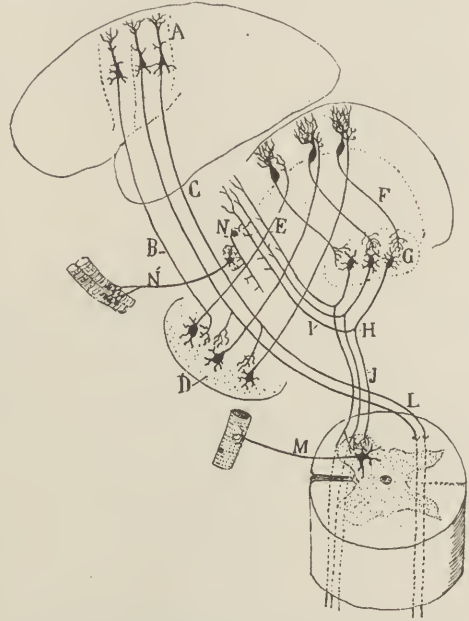


FIG. 318.—Diagram of the superior and inferior motor tracts of the cerebellum. (Cajal.)

A—Motor zone of the brain. B—Cortico-ponto-cerebellar tract. C—Cortico-spinal tract. D—Pontile nuclei. E—Ponto-cerebellar tract or middle cerebellar peduncle. F—Purkinje axones. G—Dentate nucleus. H—Bifurcation of the superior cerebellar peduncle. I—Ascending tract of Marchi. J—Descending dentato-spinal tract. L—Crossed pyramidal tract. M—Anterior root of the cord. N—Red nucleus. N'—Oculo-motor nerve.

character. Even the more active amphibians, such as the frog, are fundamentally dependent upon vermicular movement. In their larval state, locomotion resembles that of other swimming animals. The extremities when acquired have no great independence one from the other but are regulated in such a way as to cooperate almost as a single organ. In the same manner the movement of the birds, both those depending upon the wing and the running birds, require bilateral synergic control. This is especially true in flight, where the innervation of the wings must be subjected to the most exact sort of bilateral control. In the mammal, a new phase of motion is developed with the appearance of extremities, each of which has actual independence of action. An increasing degree of such independence determined the semibiped condition, and finally released the upper extremities from responsibility in locomotion. But even before this inde-

pendence of the arms was achieved in the biped, many of the quadrupeds gained the ability to control one foreleg independently of the other, and had a similar independence in the hind extremities. It was largely in consequence of these unilaterally synergic activities that the hemispheres of the cerebellum made their appearance. This fact becomes significant in the light of Bolk's investigations, which go to show that in all mammals the lobulus ansiformis in its two divisions, the anterior and posterior crura, is present, and furthermore that these parts become increasingly more complex with the increased complexity in the independent movements of each limb.

In summarizing the evolutionary significance of the cerebellum, it may be concluded:

1. That the cerebellum has been added to the neuraxis as a suprasegmental structure in the interest of coordination.
2. That in its primitive form it correlates sensory impulses received from all of the chief receptors of the body, and utilizes the impulses thus associated most advantageously to accomplish the purposes of coordination.
3. That in the lower vertebrates this coordination requires the harmonious action of the axial musculature, and depends upon the bilaterally synergic control of the central arched portion of the cerebellum, corresponding in position to the vermis, although certain lateral structures, such as the paraflocculus and flocculus, were added for the more or less independent movements of the tail.
4. That when the upper and lower extremities made their appearance and became capable of independent movements, they needed something more than bilaterally synergic control. Out of this necessity grew the expansive lateral portions of the cerebellum, the cerebellar hemispheres, which provide unilateral synergic control for the arms and legs, exercising regulation over such independent and individual movements as these extremities have the capacity to develop.
5. That, as a natural consequence, the greater the range of independent movement in the extremities, the greater has become the cerebellar area required for its control.
6. That the greatest range of independent movement is seen in the skilled performances which are the special attributes of man, who, as a result, has the most highly developed cerebellar hemispheres.
7. That the central or vermal portion of the cerebellum not only still retains its primitive control of the bilaterally synergic movements of the eyes, face, tongue, jaws, larynx, neck and trunk, but also maintains a similar relation to movements of the extremities which require bilaterally synergic control.

CHAPTER XXIV

THE CEREBELLUM

RELATIONS, SURFACE APPEARANCE AND ANATOMY

General Relations and Boundaries. The cerebellum is situated in the posterior fossa of the skull. It lies beneath the tentorium and caudal to the posterior surface of the petrosal portion of the temporal bone. In the base of the cranium it occupies all except that mesial portion of the posterior fossa which affords support to the pons and the medulla oblongata. Al-

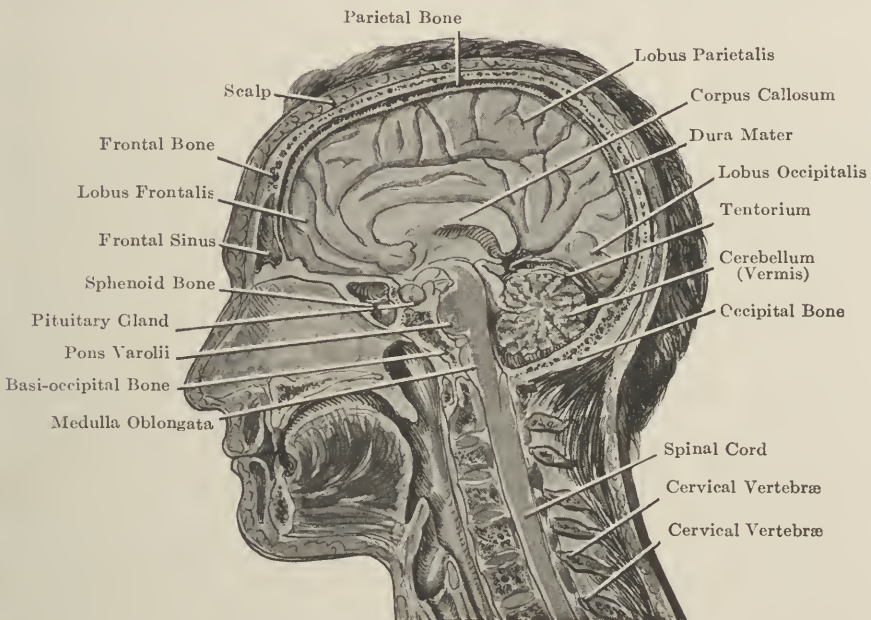


FIG. 319.—Sagittal section of brain *in situ*.

though distinguished from the segmented portion of the brain-stem by its general character, it has no well defined boundaries. A boundary line may be drawn, however, at the junction of either middle cerebellar peduncle with the cerebellum. This junction is referred to as the *hilus cerebelli*.

Surface Relations. The cerebellum by its *dorsal* or *tentorial surface* is in contact with the tentorium cerebelli, which separates it from the occipital lobe of the cerebral hemispheres. The *straight sinus* makes its way in the dura mater at the junction of the tentorium and falx cerebri in the midline above the cerebellum.

The *ventral* or *occipital surface* rests upon the dura covering the two

cerebellar fossæ of the occipital bone; in the midline it is in relation with the *occipital sinus* and the *cisterna magna*.

The *cephalic* or *petroso-ventricular surface* lies in contact with the dura mater covering the posterior surface of the petrosa, and with the roof of the fourth ventricle. The most lateral aspect of this surface is in close relation with the *sigmoid and bulbar portions* of the *lateral sinus*. It is separated from the *mastoid cells* of the temporal bone by the thin inner osseous cortex and the dura attached to the bone. This relation has especial importance in connection with suppurative processes in the mastoid cells which may, upon occasion, erode the bone and thus gain access to the cerebellum. This surface is also in intimate relation with the *internal auditory meatus* which transmits the seventh and eighth nerves. Mesial to the meatus is the jugular foramen for the transmission of the lateral sinus, the vagus and the glossopharyngeus nerves. The junction of the dorsal and ventral surfaces is indicated by a rounded border which, extending from the midline, is successively in relation with the *torcular Herophili* and the *lateral sinus*. At the junction of the ventral and cephalic surfaces, the lateral sinus turns downward to form the sigmoid and bulbar portions of this venous channel.

Dimensions, Weight and Coverings. The *greatest transverse diameter* of the cerebellum is 10 cm. Its *greatest cephalo-caudal diameter* is 5 cm. Its *greatest ventro-dorsal diameter* is 5 cm. It weighs 140 gm., or about one-tenth of the entire brain weight.

By its ventral surface, the cerebellum is in close relation with the occipital bone. The cephalic surface is in relation with the petrosal portion of the temporal bone. The dorsal surface of the cerebellum in man is in contact throughout its entire extent with the tentorium cerebelli. In certain mammals, this membranous plate is replaced by a bony structure forming an osseous tentorium. In some instances, partial ossification of the tentorium has been observed in man.

The dura mater forms a complete investment about the cerebellum. In the posterior fossa it forms the endosteum of the occipital bone and petrosa of the temporal bone. The dural investment of the cerebellum is completed by the tentorium, which is stretched across its dorsal surface.

Several special processes of the dura mater are in relation with the cerebellum. One of these, the *falx cerebelli*, is attached to the under surface of the tentorium in the midline and also to the internal occipital crest. It extends toward the foramen magnum, where it bifurcates into two processes, each of which gradually fades out along its respective margin of the foramen. The falx cerebelli is inserted between the two halves of the cerebellum in the *posterior cerebellar notch*. Its attachment to the bone in the occipital region forms the *occipital sinus*.

Another specialized process of the dura is the *lateral sinus*, which is situated at the attachment of the tentorium to the occipital and temporal bones. In and near the midline this sinus becomes dilated to form the *torcular Herophili*. Laterally it extends in both directions toward the groove of the *sigmoid portion of the lateral sinus*, where it turns directly downward

to approach and enter the jugular foramen. The tentorium is attached to the superior border of the petrosal portion of the temporal bone, and in this line of attachment forms the *superior petrosal sinus*.

The *arachnoid* affords its usual covering situated between the pia and the dura, forming a *large subarachnoid space*, which spreads about the dorsal aspect of the medulla and along the ventral as well as the dorsal surface of the cerebellum immediately adjacent to the midline. This extension of the subarachnoid space is part of the *cisterna magna*. The subarachnoid space in connection with the cerebellum elsewhere is not so ample, and makes provision only for a thin layer of cerebrospinal fluid.

The *pia mater* is a close vascular investment of the cerebellum, as it is of other parts of the nervous system. It contains the arteries and branches of the arteries which supply this organ. The membrane dips into all of the larger cerebellar fissures as well as into the primary and secondary sulci. In order to disclose the actual surface of the cerebellum, this membrane must be stripped off.

Arteries of the Cerebellum. The cerebellum receives its arterial supply from the superior cerebellar and the anterior inferior cerebellar arteries, both branches of the basilar artery. It is also supplied by the posterior inferior cerebellar arteries, branches of the vertebral arteries.

Parts of the Cerebellum. The cerebellum consists of three parts: A central portion or *vermis*, and two lateral lobes or *hemispheres*.

In man, a still further subdivision is established by following the course of the *great horizontal fissure* which divides both the vermis and the hemispheres into an upper and lower portion. The part lying above the horizontal fissure is the *superior portion* of the cerebellum, and that lying below is the *inferior portion*.

After removal from the skull and detachment from the rest of the brain-stem, the cerebellum has much the appearance of a butterfly with wings outspread. The body of the butterfly is the vermal portion, while the wings correspond to the hemispheres.

The great horizontal fissure is located by noting the position and relations of two prominent triangular areas which appear on the petroso-ventricular surface, into which the middle cerebellar peduncles enter. The apex of each triangular space is directed outward, and from this point the great horizontal fissure begins. It passes around the entire circumference of the cerebellum, dividing it into its superior and inferior portions. Sometimes, however, it is interrupted on the vermis, being deep enough only to make an incisure upon the more lateral aspect of the central portion. It is visible on the dorsal surface of the cerebellum for a short distance as it approaches the posterior notch, while in the remainder of its course it traverses the ventral and cephalic surfaces. Although important as a landmark in the description of the human cerebellum, the sulcus horizontalis cerebelli is, from the morphological standpoint, of secondary importance. It appears as a fissure developed late in man, and in many mammals is altogether wanting.



FIG. 320.—The tentorial surface of the cerebellum.



FIG. 321.—The occipital surface of the cerebellum.



FIG. 322.—The petroso-ventricular surface of the cerebellum.

Surface Appearance of the Cerebellum. After removal of the pia mater, the cerebellum presents a characteristic appearance which identifies it in all mammals and in most of the lower vertebrates. It consists of a series of fissures and sulci which run more or less regularly in parallel lines transversely across the surface. These parallel fissures are fairly close together, so that they give the surface of the organ the appearance of a series of successive narrow strips, each strip being comprised between two fissures. The area between two of these transverse sulci constitutes a *folium*. In some cases the sulci descend to a considerable depth; in other instances they are shallow. In the human cerebellum, the transverse fissures and folia extend completely across the surface. As a consequence, each folium has a vermal portion and two hemispherical representatives, one extending to the right

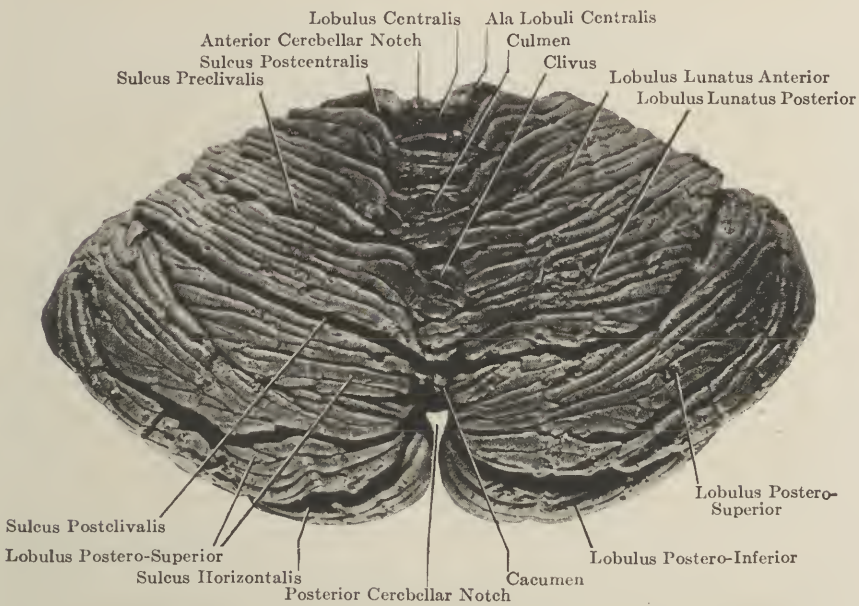


FIG. 323.—Tentorial surface of the human cerebellum showing fissures and lobes.

and one to the left. The deeper fissures constitute the lines of division which make possible the identification of certain lobes and lobules. From the anatomical as well as from the histological point of view, *the folium is the cerebellar unit of structure*.

Surfaces of the Cerebellum. The surfaces of the cerebellum have been described in several ways; but for practical purposes, three surfaces may be distinguished:

1. The *tentorial surface*, which occupies a dorsal position and takes significance from its relation with the *tentorium cerebelli*.
2. The *occipital surface*, which occupies a ventral position and is in relation with the occipital fossæ.
3. The *petroso-ventricular surface*, which occupies a cephalic position and

is in relation with the petrosal portion of the temporal bone and the roof of the fourth ventricle.

This designation of the surfaces is of value from the surgical standpoint, inasmuch as it gives the leading anatomical character of each surface which may be readily visualized and made use of in operative procedure.

The *tentorial surface* lies immediately beneath the tentorium and takes its general contour from this structure. It presents a central ridge-like elevation which extends from the cephalic to the caudal extremity of its surface. Its cephalic extremity comes into relation with a small incisure, the *anterior cerebellar notch* (*incisura cerebelli anterior*). Its caudal extremity terminates in a much larger incisure, the *posterior cerebellar notch* (*incisura cerebelli posterior*). The central ridge of the tentorial surface represents the superior

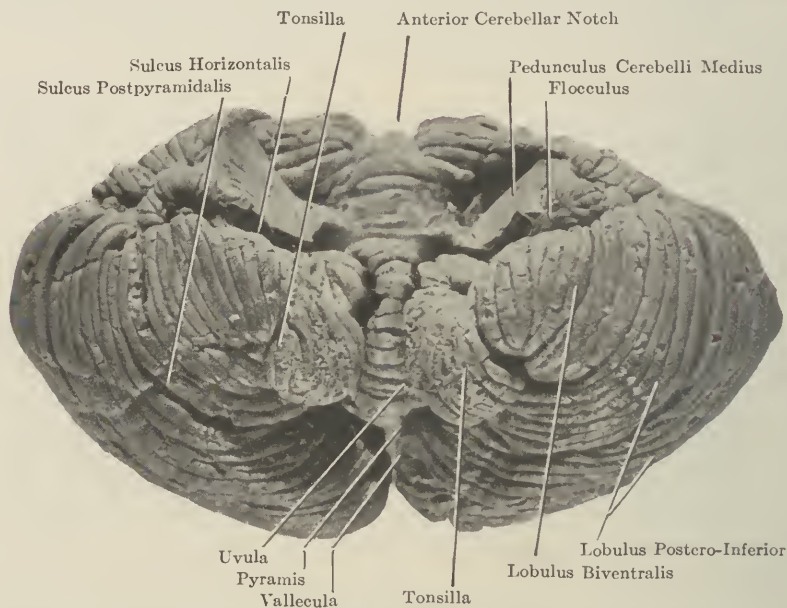


FIG. 324.—Occipital surface of human cerebellum showing fissures and lobes.

vermis which, with the exception of a very small portion, is situated entirely in this region. A smaller portion of the superior vermis, however, is lodged in the anterior cerebellar notch and brought to view upon investigation of this incisure. In the midline the ridge lies beneath the *straight sinus*. In a lateral position are the greatly expanded cerebellar hemispheres. Each folium of the vermis extends to the right and left upon this surface of the cerebellar hemispheres. In general contour the tentorial surface is concavo-convex and starting at the ridge of the vermis, the surface slopes away obliquely toward the lateral extremity of the hemispheres. The dural relation of this surface is important in surgical explorations of the posterior fossa, for if the tentorium be incised it is likely to result in either a hernia of the cerebellum into the supratentorial fossa, or, as is more often the case, a hernia of the occipital lobes into the subtentorial space.

The *occipital surface* presents two symmetrical halves separated from each other by the deep *posterior cerebellar notch*. The surfaces themselves are markedly convex, and adapt themselves to the form of the cerebellar fossæ. The vermal portion of the cerebellum is hidden in the depths of the posterior cerebellar notch, so that a continuation of the folia and fissures from hemisphere to vermis is not so regular as in the case of the tentorial surface. All of this portion of the cerebellum lies below the great horizontal fissure and consequently is in the inferior portion of the cerebellum. The occipital surface is of particular importance, because it is the portion of the organ which is revealed upon the usual surgical approach, either for exploration or cerebellar decompression. When the tables of bone upon either side of the foramen magnum which form the cerebellar fossæ

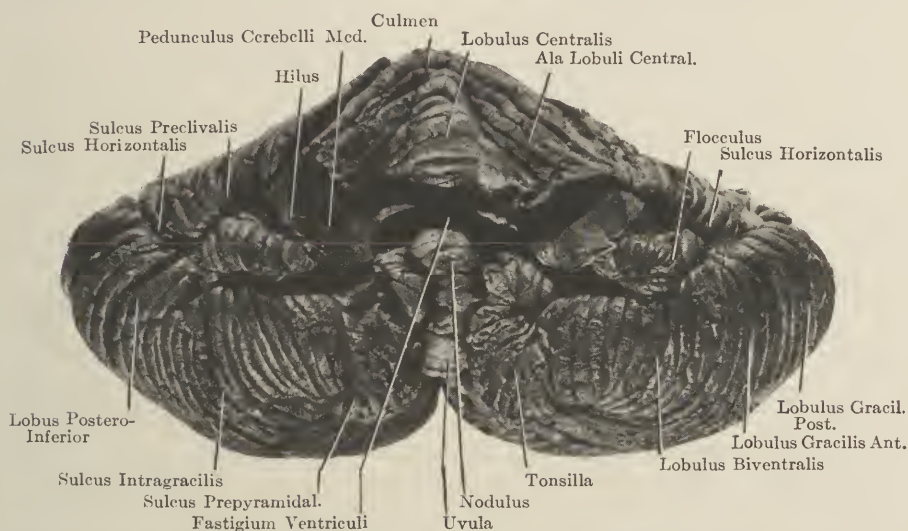


FIG. 325.—Petroso-ventricular surface of human cerebellum showing fissures and lobes.

are removed, the dura mater in this region is disclosed. Running from above downward in the midsagittal line is a small venous channel, the *occipital sinus*, which marks the attachment of the falx cerebelli to the dura covering the posterior fossa. When the portion of the occipital bone below the superior occipital crest is removed and the dura incised, the occipital surface of the cerebellum comes to view.

The *petroso-ventricular surface* occupies a cephalic position, and by its lateral two-thirds rests upon the petrosal portion of the temporal bone, while its mesial third is in relation with the roof of the fourth ventricle. In order to realize the character of the petroso-ventricular surface, it is necessary to detach the cerebellum from the pons and medulla by incision through the three cerebellar peduncles. When this is done the surface presents a central or vermal portion and two lateral hemispherical portions. The vermal portion is contained in a deep groove, the *vallecula cerebelli*, upon either side of which a fissure extends in the cephalo-caudal direction. These two fissures consti-

tute a boundary between the vermis and the hemispheres, and are known respectively as the *sulcus sinister vallecule* and the *sulcus dexter vallecule*. In the vallecule is lodged the inferior vermis, a portion of which comes into close relation with the roof of the fourth ventricle and even projects into the ventricular chamber itself. Lateral to the vallecule, the hemisphere is divided into a superior and inferior portion by means of the horizontal fissure which terminates upon this surface. The brain-stem viewed before detachment of the cerebellum shows upon either side the lateral one-third of the surface which is in relation with the petrosal portion of the temporal bone. The most prominent feature of this region is the triangular area known as the hilus, in relation with which are the three cerebellar peduncles. Its apex is continuous with the great horizontal fissure, while the base is in relation with the following structures: (1) the middle cerebellar peduncle; (2) the flocculus; (3) the seventh and eighth nerves; (4) the lateral recess.

This region is of surgical importance, since one of the most common tumors arising in connection with the brain, *neurofibroma of the acoustic nerve*, develops here. The area is also called the *cerebello-pontile angle*. The petroso-ventricular surface is in relation with the internal auditory meatus, from which emerges the eighth nerve in its two divisions on its way to enter the brain-stem, and into which passes the seventh nerve on its way toward the *Fallopian canal*.

Neoplasms of this area affect all of these structures, either simultaneously or in regular order, so that symptoms of disease in this region are those referable to compression of the seventh and eighth nerves, of the cerebellar peduncle, and ultimately of the pyramidal fibers passing through the pons.

A short distance cephalad of the cerebello-pontile angle is the collection of fibers forming the dorsal root of the fifth nerve, together with its *portio minor* or *motor division*. Caudal to the lateral recess and in relation with the seventh and eighth nerves below the bulbo-pontile sulcus are the glossopharyngeus and vagus nerves. Neoplasms of this region at times extend forward to involve the dorsal root of the fifth nerve, in which event sensory symptoms referable to the face and head are present. The tumor, however, may extend backward to involve the ninth and tenth nerves, and thus offer a serious obstacle to surgical procedure.

Cerebellar Lobation in the Human Brain. Some of the transverse cerebellar fissures are deep and serve as the boundary lines between certain recognizable lobes in the cerebellum. Each cerebellar lobe consists of three parts: first, a *central, vermal lobule*, and second, *two lateral hemispherical lobules* extending like outspread wings from the central part. Each central lobule with its appended lateral lobules has been assigned a name. The terminology applied to these parts by different authorities is somewhat varied, although each system recognizes the same divisions in the organ. A cerebellar lobe takes its name from the central, vermal lobule; for example, the *lobulus centralis* is one of the vermal lobules; its lateral appendages are the *alæ lobuli centralis*. The name of the entire lobe is the *lobus centralis*. This principle is followed in the designation of all of the cerebellar lobes,

of which there are nine, five in the superior portion and four in the inferior portion.

FISSURES OF THE SUPERIOR PORTION OF THE CEREBELLUM. The fissures of the superior portion of the cerebellum are four in number, (1) the *precentral fissure*, (2) the *postcentral fissure*, (3) the *preclival fissure*, and (4) the *postclival fissure*. The precentral fissure lies between the *lobus linguli* and the *lobus centralis*. The postcentral fissure separates the *lobus centralis* and the *lobus culminis*. The preclival fissure separates the *lobus culminis* and the *lobus clivi*. The postclival fissure separates the *lobus clivi* and the *lobus folii cacuminis*.

In addition to these large interlobal fissures, all of which extend deeply toward the medullary substance, there are other sulci on the superior portion of the cerebellum which are not well marked, but which appear on the hemispheres, although they do not make a corresponding impression upon the vermis. They are best seen in sagittal sections of the hemisphere. Of all the fissures upon the superior portion of the cerebellum, the preclival is probably the most important morphologically, since it is taken to be the homologue of the *fissura prima* of the lower mammals. In this light all the portions of the cerebellum lying cephalad of this fissure belong to the lobus anterior of comparative anatomy. It is indicative of the region in which are lodged the synergic centers for the head and face, the eyes, tongue and mouth.

FISSURES OF THE INFERIOR PORTION OF THE CEREBELLUM. The fissures of the inferior portion of the cerebellum are three in number. Beginning at the cephalic extremity, they are: (1) The *postnodular fissure*, which separates the nodule from the uvula. (2) The *prepyramidal fissure*, which separates the uvula from the pyramid. (3) The *postpyramidal fissure*, which separates the pyramid from the tuber. There are secondary, less well defined sulci which appear principally upon the hemispheres and do not make complete incisures into the vermis.

The *postpyramidal fissure*, according to Elliot Smith, is the homologue of the *fissura secunda*, and is important in marking the portion of the cerebellum which is intimately connected with the synergic innervation of the trunk and extremities.

LOBES OF THE SUPERIOR PORTION OF THE CEREBELLUM. In this portion of the cerebellum there are five lobes, namely: (1) The *lobus lingulæ*; (2) the *lobus centralis*; (3) the *lobus culminis*; (4) the *lobus clivi*, and (5) the *lobus cacuminis*.

1. *The Lobus Lingulæ.* This lobe consists of the usual subdivisions, a vermal portion and two lateral appendages constituting the hemispherical portions. As a rule, this lobe is confined to the vermis, its lateral expansions being small and atrophic. It is not evident upon the tentorial surface, as it is concealed from view by the succeeding lobe. It is best seen in median section, and consists of a small tongue-like group of four or five transverse folia which rest upon the superior medullary velum. Its medullary center is continuous with the velum and forms part of the cephalic boundary of the fourth ventricle. The lingula becomes gradually attenuated upon its lateral

aspect and has little or no representation in the hemispheres. Occasionally, the folia are continued laterally for a short distance over the lower part of the superior cerebellar peduncle forming true, although atrophic, lateral expansions, known as the *frenula linguli*.

2. *The Lobus Centralis*. This cerebellar lobe has three well-marked elements, the vermal portion and two hemispherical expansions. The vermal portion, the lobulus centralis, occupies a position in the anterior notch where it appears as a convex prominence. Its folia extend beyond the limit of the vermis for a considerable distance along the cephalic aspect of the hemispheres, where they form two wing-like continuations of the central lobule known as the *alæ lobuli centralis*. The vermal portion is made up of nine or ten folia, only five of which are visible upon the surface, the rest being concealed from view in the depths of the precentral and postcentral fissures. Upon sagittal section, the lobulus centralis is seen to receive a primary branch of the medullary substance of the cerebellum. This passes upward and forward from the enlargement of the medullary center, known as the *trapezoid body* of the cerebellum. The lateral hemispherical expansions of the lobulus centralis consist of four or five folia which are apparent upon the surface and extend forward and outward to come into relation with the hilus cerebelli.

3. *The Lobus Culminis*. The culminate lobe consists of the three usual portions, the central, vermal portion called the *lobulus culminis*, and the two lateral hemispherical expansions known as the *lobulus lunatis anterior*. The vermal portion of the culmen occupies somewhat more than half of the tentorial surface, and as its name implies, is the most prominent part of the superior vermis. It extends from the limit of the anterior cerebellar notch about halfway back along the ridge of the vermis, where it is separated from the next succeeding lobule by the preclival fissure. Its surface shows three or four primary folia with numerous secondary and tertiary laminæ in connection with them. The lateral expansion of the lobulus culminis is the *anterior lunate lobule*. It consists of from five to seven folia which appear on the surface, and is separated from the *alæ lobuli centralis* by the lateral extension of the postcentral fissure, and from the next hemispherical portion of the cerebellum by the preclival fissure. This subdivision of the superior portion of the cerebellum, the lobus culminis, constitutes the most extensive subdivision in this region. The lateral expansions each receive three well-marked divisions from the medullary centers of the cerebellum, while the vermal lobule is supplied by a common stem from the corpus trapezoideum of the vermis.

4. *The Lobus Clivi*. Caudal to the preclival fissure and extending as far back as the postclival fissure is another group of folia, the clival lobe, which consists of a vermal portion and the two lateral expansions. The lobulus clivi or central portion consists of two or three folia which appear upon the surface immediately in relation with the beginning of the posterior cerebellar notch. The lateral hemispherical expansions, however, present double this number of folia upon the surface. Each lateral expansion of the clivus is

known as the *lobulus lunatis posterior*, and the two posterior lunate lobules with the clivus constitute the *lobus clivi*. The lateral parts of this lobe receive two or three primary branches from the medullary center of the hemisphere.

5. *The Lobus Cacuminis*. The cacuminate lobe is bounded in front by the postclival fissure, and behind by the great horizontal fissure. It presents the usual divisions of a cerebellar lobe. The vermal portion lies beneath the clivus in the posterior notch and is supported by the apex of the main horizontal stem of the arbor vitæ. It consists of a single primary folium with five to seven secondary folia attached to it. The primary folium alone comes to the surface immediately above the great horizontal fissure. Its secondary folia are somewhat rudimentary in character. The lateral expansions increase rapidly in size, and present from seven to nine primary folia with numerous secondary and tertiary laminæ which produce a large hemispherical lobule at the posterior and upper part of each hemisphere, the *lobulus postero-superior*. These lobules, with the lobulus cacuminis, constitute the *lobus cacuminis*.

The clivus and probably the cacuminate lobule, lying as they do caudal to the preclival fissure, are to be homologized with the lobus simplex as that portion of the cerebellum was identified and described by Elliot Smith and Bolk. In such case, the regions referred to as the lobus clivi and the lobus cacuminis represent an area in the cerebellum which has control over the synergic centers of the neck muscles, while the area cephalad of the preclival fissure represents the anterior lobe which contains the synergic centers for the head and face, the eyes, mouth and tongue, pharynx and larynx.

LOBES IN THE INFERIOR PORTION OF THE CEREBELLUM. It is in this part of the organ that perhaps the greatest expansion has occurred in the human cerebellum, due to the great development of the synergic control of the extremities and trunkal musculature in man. Four lobes may be distinguished in the inferior portion of the cerebellum, namely: (1) The lobus noduli; (2) the lobus uvulæ; (3) the lobus pyramidis, and (4) the lobus tubercis.

1. *The Lobus Noduli*. This lobe of the cerebellum consists of the three usual parts, the vermal lobule and the two appended hemispherical lobules. In position it occupies the same relation to the inferior medullary velum of the fourth ventricle that the lingula holds to the superior medullary velum. It is, however, more developed than the lingula in its vermal portion as well as in the lateral appendages. Its central portion, the lobulus noduli, is apparent only upon sagittal section, or after the cerebellum has been separated from the neuraxis. In sagittal sections it is seen projecting into the caudal triangle of the fourth ventricle. The nodule itself consists of a single primary folium, with several rudimentary folia concealed in the depths of the post-nodular sulcus which separates it from the uvula. It receives a single stem from the medullary substance of the trapezoid body. The nodule is adherent to the median portion of the inferior medullary velum and forms the caudal

boundary of the tent-like fastigial recess of the fourth ventricle. The lateral portion of the inferior medullary velum is continued upon either side of the nodule as a thin white lamina with a thickened concave free border. This lamina has a mesial surface which is directed toward the fourth ventricle, and a lateral surface which is covered with pia mater and rests upon the tonsil. At its lateral extremity the inferior medullary velum becomes thickened, and is here covered with gray matter forming the peduncle of the flocculus which curves laterad and cephalad behind the lateral recess of the fourth ventricle to expand into an irregular lobule, the flocculus. This structure is situated between the biventral lobule and the middle peduncle of the cerebellum. Other small foliated portions of gray matter often appear behind the stalk of the flocculus. They represent the primitive *paraflocculus* which, although rudimentary in man, is present in many mammals as a structure larger than the flocculus and occupying the parafloccular fossa in the petrous portion of the temporal bone. The lobulus noduli, the vermal portion, in conjunction with the flocculus, paraflocculus and inferior medullary velum representing the hemispherical expansions, constitute the lobus noduli.

2. *The Lobus Uvulæ.* This lobe is made up of the usual three parts, the vermal lobule, the *uvula*, and the two hemispherical lobules, the *tonsils*. The uvula constitutes a large portion of the inferior vermis. It is narrow at its upper attached end, and becomes elongated as it extends backward. Its least prominent portion is in the region of the nodule, from which point it enlarges as it extends caudally and attains its greatest transverse diameters immediately ventral to the pyramid. The uvula is a median prominence separated from the tonsils by the vallecular sulci. It is separated from the nodule by the postnodular fissure and from the pyramid by the prepyramidal fissure. It consists of six or eight primary folia with a relatively large number of secondary folia, and receives a single stem from the medullary substance of the trapezoid body. The hemispherical expansions of the uvula are the tonsils, or *lobulus tonsilli*. Each lobule is an irregular ovoid body somewhat compressed from within outward, so that at times it protrudes into and occupies part of the foramen magnum. In the latter event it bears upon its outer surface the imprint of the lateral boundary of this foramen. Such compression has been considered pathological and due to intracranial pressure forcing the cerebellum into the foramen magnum. This view, however, is incorrect, since the compression is not uncommon in subjects who have had no increased intracranial pressure during life. It may be an alteration in contour due to postmortem changes. The tonsil measures about one and a quarter inches in its vertical diameter, and three quarters of an inch cephalo-caudad. It is less than one-half an inch in its transverse diameter. It occupies a deep depression in the hemisphere, the *nidus avis*. The uvula, (lobulus uvulæ) and the tonsils, (lobulus tonsilli) constitute the lobus uvulæ.

3. *The Lobus Pyramidis.* This lobe consists of the usual three parts, the vermal portion and the two hemispherical expansions. The central vermal

portion is the *pyramis*; the two lateral expansions are the *biventral lobules*. The pyramid occupies a position in the vallecule immediately caudal to the uvula, from which it is separated by the prepyramidal fissure. It is separated from the tuber by the postpyramidal fissure. The pyramid presents three or four primary folia with numerous secondary and tertiary folia connected with it. Its lateral hemispherical portions, the *biventral lobules*, present eight to ten folia upon the surface with numerous secondary folia. Each lobule receives its medullary stem from the white substance of the hemisphere, while the pyramis receives a single branch from the trapezoid body of the vermis. The lobulus pyramidis, with its two hemispherical expansions, the lobuli biventralis, constitutes the lobus pyramidis.

4. *The Lobus Tuberis*. This lobe consists of three parts, the vermal portion and the two hemispherical expansions. It constitutes the caudalmost division of the inferior vermis, and consists of two or three primary folia with five or six secondary folia. It comes to the surface immediately ventral to the lobulus cacuminis, from which it is separated by the great horizontal fissure, while it is separated from the pyramid by the postpyramidal fissure. Its demarcation from the lateral expansions is less pronounced than is the case with the other central lobules of the inferior vermis, in which particular it resembles the superior vermis. The lateral expansions of the lobulus tuberis are the *postero-inferior lobules* of the hemisphere, which lie immediately caudal to the great transverse fissure. These consist of four to six primary folia and receive their medullary stem from the central core of the hemisphere. The folia are parallel with the horizontal and postpyramidal fissures. They are subdivided by two fissures, the *sulcus intragracilis* and *sulcus postgracilis*, into the *lobulus semilunaris inferior*, the *lobulus gracilis posterior* and the *lobulus gracilis anterior*. The lobulus tuberis of the vermis with its two lateral expansions, the lobuli postero-inferiores, constitute the lobus tuberis.

TABULATION OF THE CONSTITUENTS OF THE CEREBELLAR LOBES (MODIFIED AFTER QUAIN)

CEREBELLAR SULCI	HEMISPHERAL LOBULES	VERMAL LOBULES	CEREBELLAR LOBES
1. Sulcus precentralis	1. Frenulum lingulæ	1. Lobulus lingulæ	1. Lobus lingulæ
2. Sulcus postcentralis	2. Ala lobuli centralis	2. Lobulus centralis	2. Lobus centralis
3. Sulcus Preclivalis (Fissura prima)	3. Lobulus lunatis anterior	3. Lobulus culminis	3. Lobus culminis
4. Sulcus postclivalis	4. Lobulus lunatis posterior	4. Lobulus clivi	4. Lobus clivi
5. Sulcus horizontalis magnus	5. Lobulus postero-superior	5. Lobulus cacuminis	5. Lobus cacuminis
6. Sulcus postgracilis	6. Lobulus postero-inferior, Lobulus semilunaris inferior Lobulus gracilis posterior Lobulus gracilis anterior	6. Lobulus tuberis	6. Lobus tuberis
7. Sulcus intragracilis	7. Lobulus biventralis	7. Lobulus pyramidis	7. Lobus pyramidis
8. Sulcus Postpyramidalis (Fissura secunda)	8. Lobulus tonsillaris	8. Lobulus uvulæ	8. Lobus uvulæ
9. Sulcus prepyramidalis	9. Lobulus flocculi, including the parafocculus dorsalis, parafoccularis ventralis and inferior medullary velum	9. Lobulus noduli	9. Lobus noduli
10. Sulcus postnodularis			

The Arbor Vitæ Cerebelli and the Medullary Nuclei of the Cerebellum. The internal structure of the cerebellum is best appreciated by sagittal and transverse sections of the organ. These sections disclose the general character of the cerebellum, which consists of a large central mass of medullary substance surrounded on its outer surface by a narrow layer of gray matter. The white substance has a branched appearance which accounts for the name applied to it, the *arbor vitæ cerebelli*. Embedded in the medullary substance there are certain collections of gray matter which constitute the medullary nuclei of the cerebellum.

SAGITTAL SECTION OF THE CEREBELLUM IN THE MIDLINE. This section passes directly through the middle of the vermis, the roof of the fourth ventricle and the median portion of the ventricle. It reveals the white matter in the form of the arbor vitæ branching in all directions from a cen-

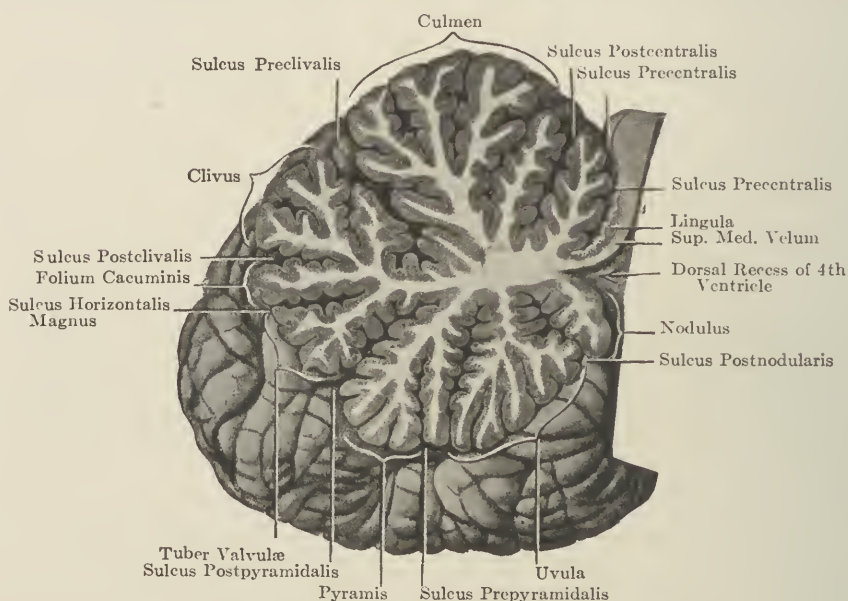


FIG. 326.—Sagittal section through cerebellum. (Quain.)

tral core, the *corpus trapezoideum*. Each branch gives off secondary and sometimes tertiary branches which are surrounded by the cerebellar cortex. The several lobular divisions of the superior and inferior vermis group themselves about the trapezoid body.

The most cephalic branch of the central core of the white matter extends forward into the superior medullary velum where it comes in relation with the rudimentary folia of the lingula cerebelli.

The next stem from the trapezoid body is short and thick; it gives off eight to ten secondary branches which enter the folia of the lobulus centralis.

Two large stem branches extend from the central core into the culmen, where they bifurcate into two secondary branches, each of which subsequently subdivides into tertiary offshoots.

The clivus, folium caecuminis and tuber each receive their branches of the white matter from a single stem connected with the trapezoid body.

The pyramis, uvula and nodule each receives a single stem from the central core, which subsequently becomes subdivided into secondary and tertiary branches.

This section shows the relation of the vermis to the fourth ventricle. The superior medullary velum is in relation with the lingula, and the inferior medullary velum is in relation with the nodule and uvula. The two vela meet at a sharp angle, forming the cerebellar or fastigial recess of the fourth ventricle; together the superior and inferior medullary vela constitute the roof of the ventricle.

SAGITTAL SECTION THROUGH THE TRANSITION FROM VERMIS TO HEMI-SPHERE. There is a general enlargement of the cerebellum in passing from

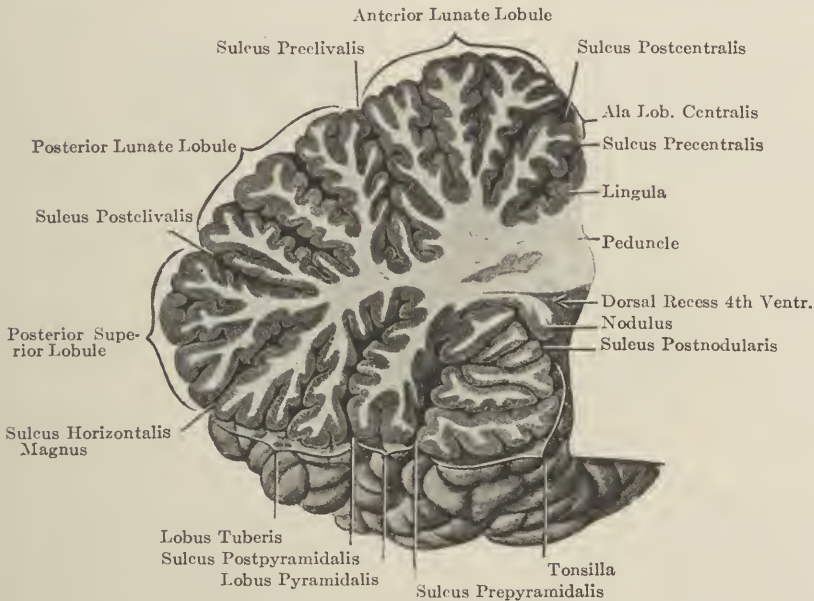


FIG. 327.—Sagittal section through cerebellum. (*Quain.*)

the vermis into the hemisphere, and in consequence the white center is much increased in size. The cephalic extremity of the trapezoid body now presents the beginning of the superior cerebellar peduncle, above which lies the lateral expansion of the lingula consisting of several irregular, rudimentary folia. The ala lobuli centralis receives a single branch from the central core, while the lateral expansion of the lobulus culminis, the anterior lunate lobe, is in connection with the trapezoid body by a heavy stem which gives rise to four secondary branches.

A single stem provides secondary branches to the posterior lunate lobule, to the postero-superior lobule, and to the postero-inferior lobule.

The pyramis receives a single stem from the corpus trapezoideum. The section passes laterad of the uvula, and consequently has taken off a small

mesial slice of the tonsil, whose folia show no direct connection with the central white matter at this level. The cerebellar or fastigial recess of the fourth ventricle is bounded above by the fibers of the superior cerebellar peduncle covered by the ependyma, and below by the nodule covered by the continuation of the inferior medullary velum.

The fissures of the cerebellum are well shown in this sagittal section. The precentral and postcentral fissures are equally deep and separate the lingula and the anterior lunate lobule from the ala lobuli centralis.

The preclival fissure extends almost to the trapezoid body, but in its depths contains three or four secondary folia not connected directly either with the culmen or the clivus.

The postclival fissure is also deep, but presents no accessory folia in its depths.

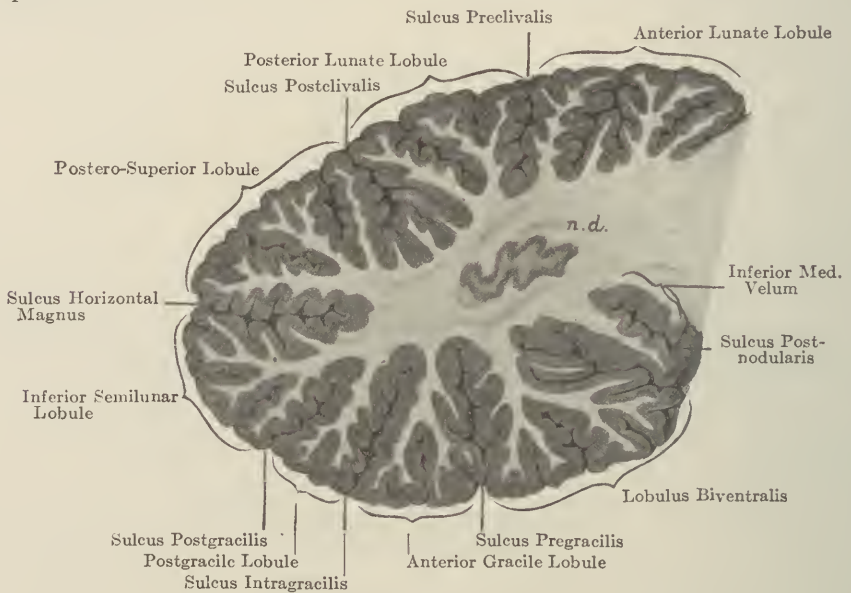


FIG. 328.—Sagittal section through cerebellum. (Quain.)

The great horizontal fissure reaches as deeply inward as the other fissures and has a slight amount of the cortex interposed between its extremity and the central white core. There are no accessory folia in its depths.

The postpyramidal fissure extends deeply inward toward the corpus trapezoideum, and in its depths presents three or four accessory folia.

The prepyramidal fissure also is deep and extends closer to the white matter than is the case with any of the other fissures. It presents one or two accessory folia.

The postnodular fissure is horizontal in position, and its internal extremity comes into close relation with the central white core. Near the center of the corpus trapezoideum is a small wedge-shaped mass of gray matter, the *nucleus emboliformis*. Situated cephalad to this nucleus is a smaller circular mass of gray matter, the *nucleus globosus*.

SAGITTAL SECTION IMMEDIATELY LATERAL TO THE VERMIS IN THE HEMISPHERE. The central core of the arbor vitæ has become greatly increased and contributes seven or eight branches to the lobules of the superior portion of the hemisphere and a number of branches to the lobules of its inferior portion. In the center of the white matter is a convoluted, ribbon-like collection of gray matter, the *nucleus dentatus*. This gray matter, enclosing a compact mass of the medullary substance, is absent near the ventro-mesial aspect of the nucleus. The absence of the gray matter, in effect, leaves an opening or *hilus* from which the fibers constituting the superior cerebellar peduncle make their way forward from the dentate nucleus.

Sections in the sagittal plane slightly more lateral in position show the lateral extremity of the dentate nucleus, which appears as a convoluted, ribbon-like mass of gray matter, surrounding a compact area of the white

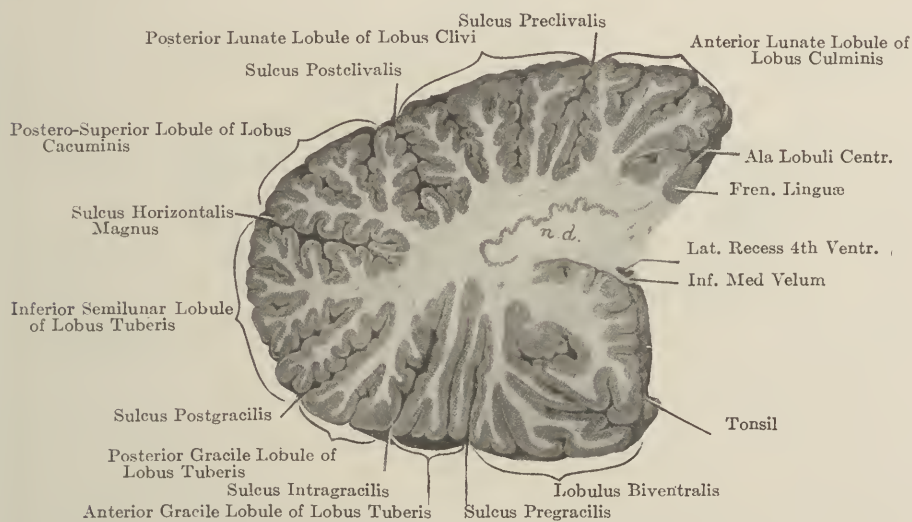


FIG. 329.—Sagittal section through cerebellum. (Quain.)

matter and itself surrounded by the medullary substance of the central core.

A section still more lateral in position than the one last mentioned shows the central white core as a massive collection of medullary substance containing no nuclei and giving off its branches directly to the principal folia of the lobules in the superior and inferior portions of the cerebellum.

TRANSVERSE SECTION THROUGH THE CEREBELLUM. A section in this plane gives a more complete idea of the relation of the central white matter to the cortex and also to the medullary nuclei. Such a section is carried through the medulla at the level of the upper limit of the hypoglossal nucleus. The medulla oblongata at this level occupies a ventral position, dorsal to which are the superior vermis, the commissura dorsalis cerebelli and some of the secondary folia of the clivus. Occupying a position ventral to these folia and at some distance upon either side from the median line, are two

small circular collections of gray matter, the *nuclei globosi*. Still further ventral, and occupying a position in the roof of the fourth ventricle, are the *nuclei tecti* (*nuclei fastigii*), the nuclei of the ventricular roof. Lateral to the nucleus globosus and the nucleus tecti is a larger wedge-shaped collection of gray matter in close relation to the hilus of the nucleus dentatus, the *nucleus emboliformis*. A commissure of fibers is seen in the small space intervening between the two nuclei tecti, the *commissura ventralis cerebelli*. This section affords a good idea of the relations of the nodule to the fourth ventricle and to the tela chorioidea inferior. The dentate nucleus contains

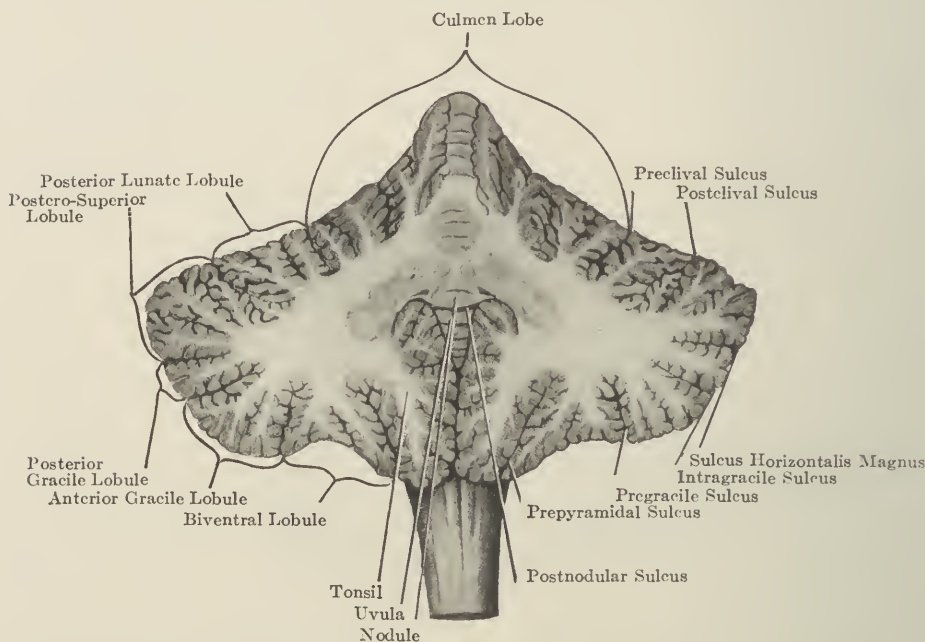


FIG. 330.—Coronal section of cerebellum about 1 cm. behind ventral wall (floor) of fourth ventricle, viewed from behind. Natural size. The lobus culminis is formed by a median elevation (culmen) and two lateral portions (anterior lunate lobules). (*J. Symington.*)

within its fundus a mass of white matter made up of axones which constitute the superior cerebellar peduncle. It is surrounded by the central core of the cerebellar medullary substance, the bundle of fibers immediately adjacent to it being derived from the inferior cerebellar peduncle, and represents axones on their way to the inferior and superior vermis of the cerebellum. The rest of the corpus trapezoideum is shown as a massive collection of white matter surrounded on all sides by the convoluted folia of the cerebellum, into which stem branches from the medullary substance extend to form a central core for each of the primary, secondary and tertiary folia connected with the several cerebellar lobules.

CHAPTER XXV

THE CEREBELLUM

INTERNAL STRUCTURE, HISTOLOGY AND EMBRYOLOGY

The histological description of the cerebellum includes the cerebellar cortex, the medullary nuclei, and the medullary substance.

THE CEREBELLAR CORTEX

The Histology of the Gray Matter of the Cerebellar Cortex. Here, as elsewhere in the central nervous system, the unit of structure is the neurone, consisting of its nerve-cell body, the *soma*; its protoplasmic processes, the *dendrites*, and its neurofibrillar process, the *axone*.

The cortex of the cerebellum occupies an ectal position, everywhere covering the central white matter. It presents a fixed arrangement throughout its entire extent and appears in two parallel rows; first, the *external plexiform or molecular layer*, which is relatively light in color; second, the *granular layer*, which upon staining appears as a dark strip running parallel with the lighter molecular layer. The cortex rests upon the *medullary layer*, consisting of the branches of the white matter derived from the arbor vitæ.

THE MOLECULAR LAYER. This layer of the cerebellar cortex occupies the most external position. It is the most uniform of the layers in point of depth. Its thickness both at the summit of the folia and in the depth of the fissures, is approximately .4 mm. Ectally, it is in relation with the pia mater, which covers the surface of the cerebellum. Entally, it is in relation with the outer aspect of the granular layer. Its essential constituents are nerve-cells and nerve fibers, the latter being present in such abundance as to account for the plexiform appearance which this layer presents. When the cerebellum is cut on an axis parallel to that of the folium, the molecular layer appears as a stratum containing a great number of fibers running in a longitudinal direction. When it is cut transversely to the long axis of the folium, it appears more definitely molecular, due to the transverse sections of many nerve fibers running through it. The molecular layer is preeminently the region of synopsis between the end-branches of axones and dendrites of cells in the cerebellum; and here the majority of connections take place in the cerebellar cortex. It contains three types of nerve cells:

1. The cells of Purkinje, the characteristic histological elements of the cerebellum.
2. The large stellate or basket cells which occupy a deep position in the molecular layer.
3. The small stellate cells which are superficial in position.

1. *The Purkinje Cells.* These cells were first described by Purkinje in 1837 and recognized by him as the histological elements which characterize the cerebellum. They are large, ovoid, semilunar or mitral in shape, and arranged in an interrupted row on the boundary line between the molecular and granular layers. Their diameters are somewhat variable in different mammals, and in man vary from 25 to 65 micra. They possess the characteristic appearance of all cells belonging to the stichochrome variety. They have a large nucleus and a small spherical nucleolus with an abundant cytoplasm containing chromophilic granules, among which a single large,

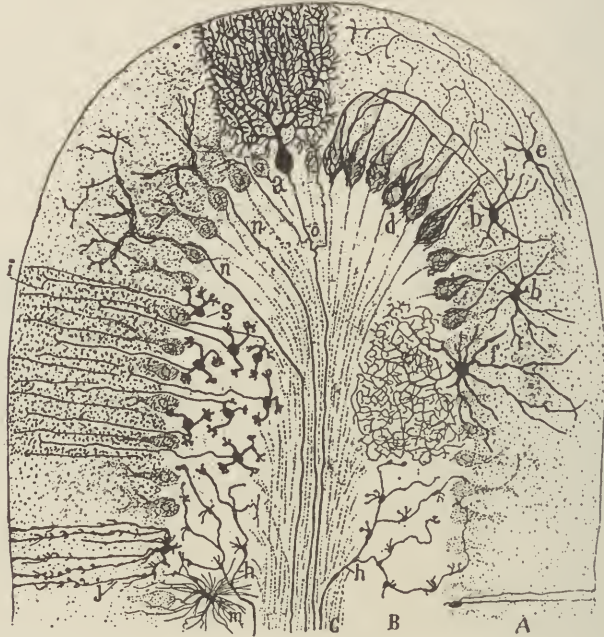


FIG. 331.—Transverse and semi-schematic section of a mammalian cerebellar convolution. (Cajal.)

A—Molecular layer. B—Granular layer. C—Stratum of white substance. *a*—Purkinje cell. *b*—Small stellate cells of the molecular layer. *d*—Descending axial end arborizations from the stellate cells, forming baskets around the bodies of the Purkinje cells. *e*—Superficial stellate cells. *f*—Large stellate cells of the granular layer. *g*—Granule cells with their axis cylinders ascending and bifurcating at *i*. *h*—Mossy fibers. *j*—Neuroglial cell. *m*—Neuroglial cell of the granular layer. *n*—Climbing fibers.

semilunar or triangular chromatic mass is usually found near the nucleus upon the side nearest the trunk of the principal dendrite. The cell has a thin cell membrane and a fine spongioplasm. The Holmgren-Golgi canals of the Purkinje cells are well developed, and a fine neurofibrillar network passes from the dendritic processes into the soma of the cell and thence into the single axone.

Processes of the Purkinje Cells. The Purkinje cell possesses dendrites which are always related to its superior pole, while its axone is connected with the inferior pole. The superior pole is directed toward the outer surface of the cortex. The dendrites are connected with the cell by one, two or,

rarely, by three trunks which are vertical or oblique in their direction. Each dendritic process subdivides in the molecular layer. This division is at first dichotomous and arciform in so far as it implicates the trunk. The dendritic trunk has no spines or gemmules upon it. Secondary and tertiary branches are given off, and from these, innumerable end-branches. The end-branches are rich in gemmules. The plane of branching of the dendrites is transverse to the long axis of each folium, so that a cross section of a folium at right angles to its long axis will reveal the Purkinje cell and all its dendritic branches, while a section parallel with the long axis shows

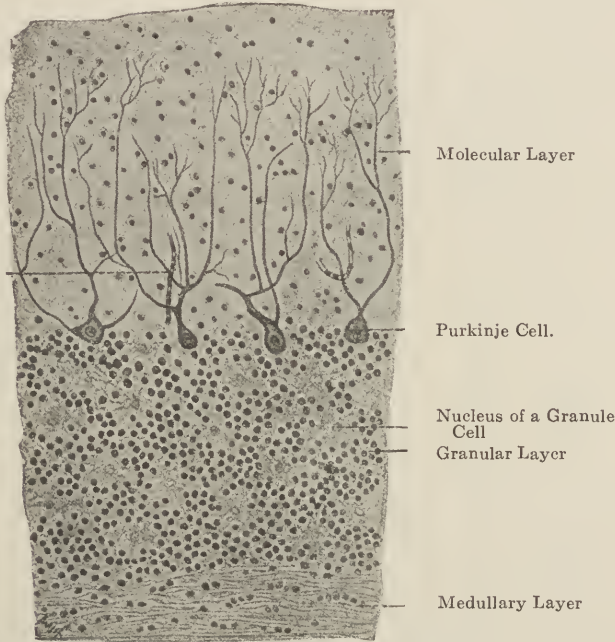


FIG. 332.—Section through a cerebellar folium.
(Bohm and von Davidoff.)

the Purkinje cell, and some of its protoplasmic processes. This disposition of the Purkinje dendrites bears an important relation to the fibers which form the molecular layer. The direction of these fibers is parallel to the axis of the folium and they consequently have the best opportunity to come into synaptic contact with many end-branches of the Purkinje cells.

The axone of the Purkinje cell which enters the white matter arises, as in the case of all nerve cells, from an axone-cone or axone-hill. This cone, however, is not so well defined as in many other motor cells, since the retraction of the Nissl bodies here is less marked. The axone-hill is not always exactly at the inferior pole of the cell, but may be placed somewhat to one side. The axone at first has no myelin sheath and only becomes myelinated after passing through the pericellular basket which surrounds the cell. It gives off several collaterals just after passing out of the Purkinje bas-

ket. These collaterals form two concentric plexus in the neighborhood of the Purkinje cells, one of secondary collaterals, the other of tertiary collaterals. The Purkinje cells are arranged in a single row between the molecular and granular layers. In some animals, particularly in the guinea-pig, there is sometimes a displacement of the Purkinje cells into a more superficial position in the molecular layer.

2. *The Large Stellate or Basket Cells.* These cellular elements are polygonal, triangular or stellate in shape. They measure from 10 to 20 micra in diameter and occupy the internal one-third of the molecular layer. They have a vesicular nucleus with a circular nucleolus, and a large amount of cytoplasm containing many fine Nissl bodies.

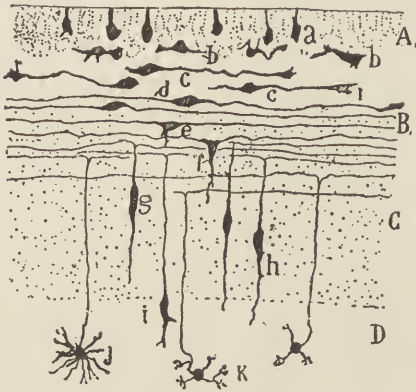


FIG. 333.—Diagram arranged to show all the forms and all the positions taken by the granules during their evolution. (Cajal.)

A—Layer of indifferent cells. B—Layer of granules at the stage of horizontal bipolarization. C—Plexiform layer. D—Granular layer. *b*—Commencement of the formation of the granule cells. *c*—Unipolar stage. *d*—Bipolar stage. *e*, *f*—Appearance of the descending dendrite. *g*, *h*—Stage of vertical bipolarity. *i*, *j*—Embryonic granule cells. *k*—Perfect granule cell.



FIG. 334.—Stages of growth of the dendrites in the granule cells. (Cajal.)

a—Vertical bipolar. *b*—Bipolar, supplied only with polar and somatic dendrites. *c*—Bipolar supplied with polar and somatic dendrites. *d*—Granule sending out numerous unramified processes. *e*—Granule at a more advanced stage, the processes having become atrophied. *f*—Appearance of the digitiform branches and the displacement of the original axis cylinder. *g*—Adult granule cell.

The dendrites of the basket cells also lie in the inferior third of the molecular layer. Each cell has from three to five dendrites which give off ascending, descending and horizontal branches. The descending branches are few and short. The horizontal branches are longer and thicker than the descending ones, while the ascending branches are most voluminous and extend toward the surface of the folium. They bifurcate several times during their course.

The axones of the basket cells were first discovered by Golgi and described by him in 1886. They extend a considerable distance in the molecular layer. Their course is horizontal and parallel to the surface of the folium. The axone gives off ascending and descending collaterals; the ascending collaterals are few in number and small in size, while the descending collaterals are large and numerous. Their course is always the same, and at regular intervals they form nets or baskets in which the cells of Purkinje

are lodged. It is from this fact that these cells are known as the *basket cells of the molecular layer*.

3. *The Small Stellate Cells.* These cells are small, oval or polygonal in shape. They occupy the outer third of the molecular layer and are present in two varieties; first, small cells with divergent dendrites and finely varicose spines upon the end-branches, whose axones are fine and short without any fixed course, while the second variety is a larger cell, stellate or triangular in shape with large dendrites. The axone also runs a long irregular course in the superficial portion of the molecular layer.

THE GRANULAR LAYER. Internal to the molecular layer is the granular layer which has a brownish tint in the fresh specimen and stains deeply in histological preparations. It is thickest at the summit of each folium and becomes considerably attenuated near the bottom of the sulci. It is sharply defined from the superimposed molecular layer, but is less clearly distinguishable from the underlying medullary substance. The granular layer contains two chief types of cells: (1) The granule cell, and (2) the stellate cell of Golgi.

1. *The Granule Cells.* These cells are very small, measuring from 7 to 10 micra in diameter. They are so numerous and closely packed together that they give this layer its distinctive granular appearance. They have a large nucleus surrounded by a very small amount of cytoplasm. A characteristic feature is their bifurcated axone. Each cell has from three to six very short dendrites which terminate a short distance from the cell in a limited arborization. A number of these arborizations are collected together in a group which forms the *dendritic islands* or *granular cytoplasmic islands*, also known as the *cerebellar glomeruli*. The axone of the granule cell may arise from the body of the cell, but more often it takes origin from one of the dendrites. It then passes perpendicularly through the granular layer into the molecular layer where, at different levels, it forms a T- or Y-shaped bifurcation, the branches of which run in either direction parallel to the surface. This arrangement of the axone of the granule cell makes it possible for it to connect with the dendritic processes of many Purkinje cells. These branches pass in either direction like telegraph wires which, at regular intervals, come in contact with the cross-trees of the telegraph poles. The cross-trees may be represented by the dendritic processes of the Purkinje cells, while the point of contact between the wire and the cross-tree would indicate the synaptic arborization between the Purkinje end-brush and the end-brush of collaterals of the granule cell. The axones of the granule cells extend into the superficial, deep and intermediate levels of the molecular layer, from all of which positions they give rise to their typical T-shaped or Y-shaped branching. In this way the molecular layer is filled at all levels with the branches of the granule cells. The axones of the granule cells are devoid of myelin sheaths throughout their entire course. The type of synaptic union between the axones of the granule cells and the dendrites of the Purkinje cells is the cruciform variety of the axo-dendritic synapsis. These connections establish extensive isodynamic series of Purkinje cells in each folium, which may be brought into action by the granule cells.

2. *The Stellate Cells of Golgi.* Three varieties of the stellate cells of Golgi are recognized in the granular layer. The most important are the large stellate cells or *corpuscles of Golgi*. These vary in number but are never numerous. They lie close to the outer margin of the granular layer and possess a cell body of irregular stellate form measuring from 10 to 15 micra in diameter. They have a large number of dendrites, four to six usually, which branch richly and extend into the molecular layer. The axone is the distinctive feature of these cells because of its unusual shortness and its rich arborization at a short distance from the cell. The end-branches of the axone come into relation with the cerebellar glomeruli.

The second type of Golgi cell found in the granular layer consists of fusiform, horizontal cells which possess one or two dendritic processes and a relatively short axone. The third type is that of the stellate cells with

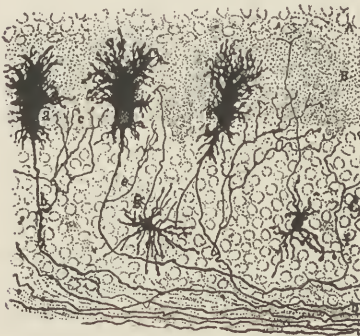


FIG. 335.—Purkinje cells at a very early embryonic stage in a new-born dog. Golgi's method. (Cajal.)

A—Superficial granules. B—Plexiform layer. C—Deep granules. D—White substance. a—Purkinje cell. b—Collateral of its axis cylinder. g—Embryonic granule cell.

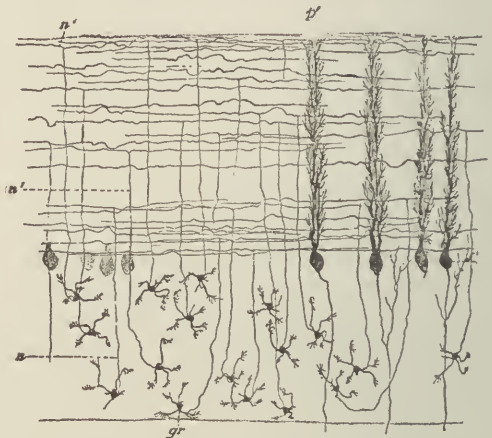


FIG. 336.—Cerebellar cortex. (Cajal.)

gr—Granule cell. n—Axone of a granule cell. n'—Bifurcating process of a granule cell. p, Purkinje dendrites.

a long axone which extends through the granular layer and into the molecular layer.

Summary of the Cellular Elements in the Cerebellar Cortex. The *molecular layer* contains:

1. The Purkinje cells, whose axones enter the medullary substance and whose dendrites occupy the molecular layer.

2. Deep stellate or basket cells, whose axones form baskets around the bodies of groups of Purkinje cells, and whose dendrites branch in the molecular layer.

3. Superficial stellate cells, whose axones run irregular courses through the molecular layer and whose dendrites branch in this same area.

The Purkinje cells carry impulses away from the cortex of the cerebellum, while the basket cells and superficial stellate cells serve to bring small groups of Purkinje cells into coordinate relations.

The *granular layer* consists chiefly of the granule cells whose dendrites are short and confined to their own layer, but whose long and bifurcated axones form the chief fiber-constituents of the molecular layer.

These cells conduct impulses received by them to a large series of Purkinje cells.

The stellate cells of Golgi have dendrites which branch extensively in the molecular layer, and come in contact with the axones of the granule cells, while their own short axones end in the cerebellar glomeruli, thus connecting with the dendritic processes of the granule cells. These cells of Golgi seem to form a short circuit for impulses passing from the granule cell back again to the same source from which they arose. The other stellate and fusiform cells of the granular layer may act in a similar capacity.

The Histology of the White Matter of the Cerebellar Cortex. The greater portion of the cerebellar cortex consists of nerve-cells, but in the molecular layer there is a considerable amount of white matter. Many fibers also enter the granular layer. The white matter of the cerebellar cortex is composed of axones of three different types: (1) *Efferent axones from the Purkinje cells* which make their way through the granular layer to the medullary core of the folium; afferent axones which consist of (2) *mossy fibers* and (3) *climbing fibers*.

The mossy fibers represent the terminal branches of afferent axones which come to the cerebellum through the cerebellar peduncles, and upon reaching the granular layer break up into a number of end-branches each of which has a small end-tuft. These tufts account for the name "mossy fiber;" they come into relation with the short dendritic processes of the granule cells and form synaptic connections with them. The type of synapsis determined by this connection is *terminal axo-dendritic*. In this manner impulses coming to the cerebellum are distributed to a large number of granular cells and thence, by means of their axones, into the molecular layer where they reach the dendritic process of the Purkinje cells.

The climbing fibers, so named by Cajal on account of their vine-like course, ascend through the granular layer to the molecular layer where they entwine themselves about the primary and secondary dendritic branches of the Purkinje cells. These fibers form individual and direct communications with the large efferent elements of the cerebellar cortex.

The mossy fibers distribute impulses which activate large groups of Purkinje cells by means of their extensive connections through the granule cells, while the climbing fibers distribute impulses which activate individual Purkinje cells.

Axones within the cortex of the cerebellum come from four main sources, the chief of which is the granule cells whose axones make up most of the molecular layer. These fibers bring a great number of Purkinje cells into coordinative activity. The second source of intracortical axones in the cerebellum is the basket cells, whose axis cylinders, situated in the molecular layer, serve to bring limited groups of Purkinje cells into play. The third source is the superficial layer of stellate cells in the molecular layer which

act in a manner similar to the basket cells; and the fourth source is from the stellate cells of Golgi in the granular layer.

Mechanisms Activating the Purkinje Cell. The Purkinje cell is motor in type and may be assumed to be the beginning of the efferent pathway from the cerebellum. From its several varieties of connection with other cells, it seems probable that it is capable of exerting its influences in several different ways. It may receive impulses from the climbing fibers, the basket fibers, the fibers of the granule cells, and from its own recurrent collaterals.

The climbing fibers represent axones from the middle or inferior cerebellar peduncle, and convey impulses either from the cerebral cortex or from the proprioceptors of the body, which latter include the receptors in the muscles, bones and joints, and also those in the semicircular canals, the utricle and saccule. Stimulation of the Purkinje cells through the climbing fibers is limited to a small group. The impulses transmitted by this means come in large part from the cerebral cortex and serve in coordinating the fine adjustments of acts requiring movement limited to small groups of muscles.

The Purkinje cells may also be brought into play through the basket fibers whose cells are stimulated by impulses received from the granule cells. This would make possible a larger grouping of Purkinje cells in the coordination of more extensive acts requiring the cooperation of several correlated muscle groups.

The axones from the granule cells establish the most extensive combinations by stimulating the greatest possible number of Purkinje cells, and thus may serve for the most extensive synergic control in such acts as require not merely movements of the arm and hand, but the combined movements of the arms, the trunk and the legs. A motor act of this sort is well illustrated in the throwing of a ball, in which practically the whole body requires the most careful sort of coordinative adjustment. In extensive control of this kind the granular cells afford a means of combination among the Purkinje cells which would have a total or general coordinative influence over the entire musculature of the body.

The probable function of the stellate cells of Golgi in the granular layer is of much interest. According to Cajal, these cells serve in the manner of a continuous circuit from the granule cells back to the granule cells again, thus producing a mechanism for the accumulation of nervous energy. The cell having a short axone may serve to store up nerve force, and when stimulated may liberate a quantity of latent force. This theory is based upon the observation that the neurones having short axones are abundant in the corpus striatum, in the cerebral cortex, in the cerebellum and in the optic thalamus, but they are almost entirely absent in the spinal cord and brain-stem. The segmented parts of the central axis are active in the production of relatively simple reflexes whose duration is short, while the higher portions of the brain determine more complex associations, such as memory, ideation and judgment.

The Golgi cells diminish both in size and number in the lower verte-

brates, which seems to be another argument for the belief that the cells with short axones serve to accumulate nerve energy for the purpose of a less immediate distribution or else for distribution in richer combinations.

THE MEDULLARY NUCLEI OF THE CEREBELLUM

Situated in the central core of the medullary substance of the cerebellum are four nuclear masses which differ from the cerebellar cortex in the fact that their cells and fibers present no stratification. They resemble the cell collections observed in the nuclei of other parts of the central axis. The medullary nuclei of the cerebellum are: (1) the nucleus dentatus; (2) the nucleus emboliformis; (3) the nucleus globosus; (4) the nucleus tecti or fastigii.



FIG. 337.—*A* and *B*, the medullary nuclei of the cerebellum.

The Nucleus Dentatus. This nucleus is the largest and most important of the medullary nuclei. It consists of a convoluted sac of gray matter in many respects resembling the inferior olive of the medulla oblongata. It encloses a fairly large space in its fundus which contains the myelinated axones constituting the superior cerebellar peduncle. On its mesial surface it presents an opening, the hilus, through which these fibers emerge. The nucleus is situated in the hemisphere close to the vermis. It has its long axis directed forward and somewhat inward. The cephalic extremity of the nucleus reaches as far forward as a transverse plane passed through the precentral fissure. Laterally, it extends about to the middle of the hemisphere.

Mesially, it comes into close relation with the fourth ventricle in whose lateral wall it causes a slight elevation, the *eminentia nuclei dentati*. Its longest diameter is dorso-ventral in direction and measures from 15 to 20 mm. Its greatest transverse diameter is about 10 mm. The cells in the nucleus dentatus are arranged in six to ten rows placed closely together and in a regular formation. They vary in size from 22 to 35 micra, having an abundant cytoplasm and large Nissl bodies. In form, the cells are stellate or triangular; they are multipolar, and their dendrites are confined to the nucleus. The cell is of the motor type. Its axone extends into the superior cerebellar peduncle. Smaller cells are scattered among larger ones; these have short axones and are undoubtedly cells of Golgi type II. Afferent fibers from the Purkinje cells form pericellular nets about the cells in the dentate nucleus. Scattered among these cells are the two chief types of neuroglia, the *astrocytes* and the *neuroglial cells* with short processes.

The Nucleus Emboliformis. This is an irregular wedge-shaped mass of gray matter lying close to the hilus of the dentate nucleus, occupying much the same relation that the median accessory olive holds to the hilus of the inferior olive. Its largest sagittal diameter is 15 mm.; its vertical diameter is 4 mm., while its thickness decreases from 3 mm. at its cephalic extremity down to the slender tip of the wedge at its caudal extremity. The nucleus emboliformis rests upon the superior cerebellar peduncle and its cephalic extremity extends as far forward as the plane of the precentral fissure. Histologically, it resembles the dentate nucleus except that its cells are somewhat smaller. Their axones make their way into the superior cerebellar peduncle.

The Nucleus Globosus. This nucleus lies mesial to the nucleus emboliformis, between the latter and the nucleus tecti. In form it is generally globular; its greatest transverse diameter is 5 mm. Histologically, it resembles the nucleus emboliformis and its axones enter the superior cerebellar peduncle.

The Nucleus Tecti or Fastigii. This nucleus is better defined than either the nucleus globosus or emboliformis. It lies in the central white substance of the vermis in the lower portion of the corpus trapezoideum, close to the midline and to its fellow of the opposite side. In its general form the nucleus is ovoid, with its caudal pole somewhat elongated. In its greatest sagittal diameter it measures 10 mm.; its transverse diameter is 5 mm. The nucleus extends from the base of the lingula to the stem which supplies the pyramid. It is closely related with the corresponding nucleus of the opposite side by means of the commissural fibers constituting the *commissura ventralis cerebelli*, and takes its name from the fact that it is situated in the roof of the fourth ventricle. The cells in this nucleus are of large size. They are rounded or triangular in form. Their dendrites are long and branch frequently; their axones extend into the juxta-restiform body, while afferent fibers appear to make their way to these cells through this same structure. The roof nucleus is connected with the vestibular nuclei by the vestibulo-cerebellar tract, and also with many parts of the cerebellar cortex.

All of the medullary nuclei of the cerebellum are well developed in the anthropoid apes and man. The nucleus dentatus, nucleus emboliformis, nucleus globosus and nucleus tecti may be identified in the gorilla, orang-outang and chimpanzee; but in the lower primates these nuclei lose much of their characteristic appearance and are present as more diffuse and less well defined nuclear masses situated in the white matter. In the lower mammals their definition is less distinct than in the lower apes. It is difficult to establish the homologies between the central cerebellar nuclei of the birds and the medullary nuclei of the cerebellum in mammals. It is probable, however, that the nucleus tecti of mammals is the equivalent of the nucleus internus in birds. The nucleus emboliformis corresponds to the avian nucleus intermedius, while the nucleus dentatus of mammals has its probable homologue in the nucleus lateralis of birds. No nuclear structures which exactly correspond to the nucleus tecti, nucleus dentatus and nucleus emboliformis have as yet been identified in the lower vertebrates.

THE MEDULLARY SUBSTANCE OF THE CEREBELLUM

The white matter of the cerebellum is found in the large central medullary core and also in the primary, secondary and tertiary branches derived from this source. It is made up of afferent and efferent axones making their way to the cells of Purkinje or leaving them for other destinations. In addition to the fibers comprising the afferent and efferent axones, certain subdivisions of the medullary substance are recognized:

1. The *subcortical or association layer*, varying from .2 to .5 mm. in thickness, extends beneath the granular layer parallel to the surface and into the bottom of the deeper fissures. This provides the means of association and connects the folia and lobules of the same hemisphere.

2. The *commissural tracts*, of which the superior cerebellar commissure, situated in front of the dentate nucleus, is the larger. The inferior cerebellar commissure passes behind the roof nucleus and consists of a small number of transverse bundles. The fibers connect the two cerebellar hemispheres.

3. The *commissure of the roof nuclei* constitutes a connection distinct from the cerebellar connections just mentioned. The bundles traverse the cephalic portion of the roof nucleus, and serve chiefly as an internuclear connection.

4. The *median sagittal bundle*, which extends from the superior medullary velum beneath the roof nucleus into the medullary substance of the vermis. These fibers are continuous cephalad through the frenulum into the inferior colliculi.

Connections of the Cerebellum. The cerebellum is connected with the segmental and suprasegmental portions of the nervous system by means of three pairs of peduncles: (1) The inferior cerebellar peduncle or restiform body; (2) the middle cerebellar peduncle, and (3) the superior cerebellar peduncle.

Two of these peduncular connections convey principally afferent impulses

to the cerebellum, *i.e.*, the inferior and middle peduncles; while the superior cerebellar peduncle is, in the main, efferent in its character, providing the principal pathway for the cerebellar impulses which are to be distributed to the muscles.

THE INFERIOR CEREBELLAR PEDUNCLE. This structure consists of a massive tract of fibers connecting the spinal cord and medulla with the cerebellum. It therefore presents a spinal and a bulbar division. The chief constituents of this peduncle are:

1. The *direct cerebellar tract*, the fibers of which arise in Clarke's column, pass upward in the cord, to end in the cortex of the anterior part of the superior vermis on the same side. Some fibers reach the opposite side of the vermis by way of the superior commissure. This tract serves to convey impulses from the proprioceptors of the limbs and trunk.

2. The *arcuate fibers*; both the posterior and anterior of which arise in the nucleus gracilis and nucleus cuneatus of the opposite and the same side and enter into the formation of the inferior cerebellar peduncle. These axones end in the cortex of the superior vermis of the same and opposite sides.

3. The *olivo-cerebellar fibers*, arising in the opposite inferior olive and to a limited extent in the olive of the same side, form the lateral portion of the restiform body, end in the cortex of the hemisphere and vermis, as well as in the fiber capsule enveloping the nucleus dentatus. Most of the fibers in this connection are afferent. It is possible, however, that some axones are efferent and conduct impulses from the cerebellum to the olive.

4. *Fibers from the nucleus lateralis of the medulla*, which pass to the cortex of the cerebellar vermis.

5. *Fibers from the arciform nucleus*, which pass to the cerebellar cortex of the opposite side.

6. The *nucleo-cerebellar tract*, comprising fibers from cells in the reception nuclei of the trigeminal, vestibular, facial, glossopharyngeal and vagus nerves. The tract occupies the mesial portion of the peduncle and ends in the nucleus tecti of the same and opposite sides.

7. *Other fibers pass in the reverse direction* from the roof nucleus to the dorso-lateral vestibular nucleus (nucleus of Deiters) and thence by the Detero-spinal tract to the medulla and spinal cord.

8. *Additional vestibular and possibly other sensory fibers* pass without interruption by way of the restiform body to the roof nuclei and constitute the direct sensory cerebellar tract. The majority of these fibers enter into the formation of a discrete fasciculus mesial to the inferior cerebellar peduncle, the juxta-restiform body.

THE MIDDLE CEREBELLAR PEDUNCLE. This connection, an afferent one, is also known as the *brachium pontis*. It is a continuation of the pons into the medullary portion of the cerebellum, and transmits impulses arising in the frontal, parietal, occipital and temporal areas of the cerebral cortex. It does not establish a direct means of communication but, by relay in the pontile nuclei, completes the pallio-ponto-cerebellar connection. The chief constituents of the middle cerebellar peduncle are the ponto-cerebellar fibers

forming the continuations of the tracts connecting the frontal, temporal, occipital and parietal areas of the cerebral cortex with the pontine nuclei.

These fibers take origin in cells of the frontal, temporal, occipital and parietal lobes respectively. They descend through the internal capsule and the cerebral peduncle to end in the cells of the pontile nuclei. From these cells arise the ponto-cerebellar fibers, which decussate in the pons and convey impulses to the hemispheres, to the vermis and possibly to the dentate nucleus of the cerebellum. Cerebello-pontile fibers have been described, but their existence is by no means well established. The assumption that many efferent cerebellar fibers end around the cells of the pontile nucleus lacks the support of recent investigation.

THE SUPERIOR CEREBELLAR PEDUNCLE. This peduncle forms the pathway by means of which the cerebellum exerts its influences over the muscles and distributes impulses to other destinations. Together with its fellow of the opposite side, it undergoes a complete decussation before reaching its next relay station, the *red nucleus* of the midbrain. Its chief constituents are the *cerebello-rubral tract* and the *cerebello-thalamic tract*. It also contains a *cerebello-tegmental tract*. The principal elements of the latter fasciculus are fibers which arise in cells of the dentate nucleus, emerge from its hilus, receive augmentations from the roof nucleus and become consolidated as a rounded bundle. After passing cephalad in the lateral wall of the fourth ventricle, the superior cerebellar peduncle sinks ventrally and disappears beneath the inferior colliculus. Many of its fibers continue their course through the tegmentum of the midbrain into the subthalamic region of the diencephalon. Before reaching the level of the red nucleus the peduncle undergoes decussation, thereby establishing a contralateral connection between the dentate and rubral nuclei. After decussation, the peduncular fibers form a capsule which surrounds the red nucleus. Many of the fibers entering into this capsule penetrate and form synapses in the nucleus ruber. This establishes a crossed dentato-rubral connection. The cells of the red nucleus give rise to descending axones which, immediately upon leaving their nucleus of origin, undergo complete crossing to the opposite side in the *ventral tegmental decussation of Forel*. The fibers then become collected to form a descending fasciculus, the *rubro-spinal tract of Monakow*. By means of this double decussation, first in the superior cerebellar peduncle and then in the ventral crossing of Forel, the cerebellum exercises an ipsilateral control over the muscles of the body.

Some peduncular fibers which participate in forming the capsule of the red nucleus either pass directly forward to the subthalamic region or are first relayed in the nucleus and then enter the subthalamus. The significance of this dentato-subthalamic connection is not clear. It furnishes the possibility of a cerebello-subthalamo-cortical pathway for the communication to the cerebral cortex of impulses concerned in equilibratory sensibility.

DEVELOPMENT OF THE CEREBELLUM

The Cerebellar Plates and Rhombic Lip. The cerebellum takes origin in the alar plates of the metencephalon. At the end of the first month in the

human embryo, these plates cephalad of the pontile flexure are somewhat thickened and present a moderately convex surface toward the ventricle. The thicker portions constitute the two cerebellar plates or ridges, in each of which a mesial and a lateral area may be identified. The mesial area comprises the bulk of the alar plate, while the lateral area marks the transition between the lateral wall and the attenuated roof-plate. This is known as the *rhombic lip*, a structure of much importance in the development of the cortex of the cerebellum.

During the second month the alar plates increase greatly in size, due to the proliferation of the cells of the mantle layer, and protrude still further into the ventricle. They come to lie as two transverse ridges, assuming this new position because of the increase of the pontile flexure. Inasmuch as the space in which they are permitted to grow is limited, the cerebellar plates begin to extend outward and to make their appearance upon the surface of the neuraxis above the hindbrain. The two plates soon meet in the midline, where they fuse and produce a swelling which corresponds to the vermis.

The Lateral Lobes and Vermis. By the third month, the cerebellum consists of two lateral lobes connected across the midline by the vermis. In the latter, certain fissures have made their appearance and thus differentiate the pyramid, the uvula and the nodule. These fissures are at first confined exclusively to the vermis.

By the fourth month the fissures have extended to a considerable degree into the lateral lobes. At this period the entire vermis lies in the same plane, although the divisions of the superior vermis present a slight inclination from above downward and forward. Secondary sulci make their appearance, and the nodule becomes definitely connected with the flocculus and para-flocculus by means of the floccular stalk, while the inferior vermis is beginning to turn ventrad into a more intimate relation with the cavity of the fourth ventricle. At this period, all the larger fissures of the vermis have extended into the cerebellar hemispheres, and many secondary fissures are discernible in these structures. The fissura prima and fissura secunda, as well as the sulcus horizontalis magnus are now well defined. The vermis presents the following parts: (1) The nodule; (2) the uvula; (3) the pyramid; (4) the tuber; (5) the folium; (6) the clivus; (7) the culmen; (8) the central lobule, and (9) the lingula.

The hemispheres have expanded rapidly, and there is a still more marked inclination on the part of the inferior vermis to turn forward into its ultimate relation in the fourth ventricle.

Migration of Cells from the Rhombic Lip. During the early stages of development, the walls of the neural tube, represented in the alar plates, show the typical three layers. The cells in the ependymal and mantle layers, however, do not develop as rapidly as in other parts of the neuraxis. Cells from another source in the cerebellar plate give rise to the cortex of the cerebellum. As the two lateral plates draw together and fuse, the rhombic lip is brought into approximation and finally fuses across the midline in the region overlying the portion of the vermis which is ultimately to become the nodule.

The Cortical Lamina. By the end of the third month, the ependymal cells in the deeper areas of the cerebellar plates have ceased their proliferation, while the ependyma of the rhombic lip has become disposed as a thin film across the outer surface of the nodule and flocculus. Here the process of mitosis is going on more actively than in any other part of the cerebellum, forming a thin sheet, the cortical lamina. By a gradual extension this lamina spreads forward over the cerebellar plates until it has covered the entire exposed surface of the cerebellum. When the fissures begin to appear, the cortical lamina dips down into them and the cerebellar surface thus receives a secondary outer coating by the progressive invasion of cells derived from the ependyma of the rhombic lip.

At the end of the fourth month, the secondary invasion has reached as far forward as the superior medullary velum. It constitutes a thin cellular film known as the *stratum moleculare*. Shortly after this stratum begins to make its progressive invasion forward, it is followed by a second deeper layer which advances along a line parallel with it and ultimately reaches as far forward as the superior medullary velum. This invasion gives rise to the *stratum granulare*. The two strata establish the foundations for the development of the cortex of the cerebellum. The differentiation of the cerebellar gray matter thus results from a developmental process quite different from that observed in the portions of the neuraxis already considered. In substance, this process depends upon the conversion of the non-cellular marginal zone into a cortex by means of invasion by the cells arising in the rhombic lip. It is possible that some migration may take place from the mantle layer, and thus aid in the formation of the cerebellar cortex.

The Cells of the Cerebellum. The differentiation of the granule cell passes through four phases: (1) The phase of germinal indifference; (2) the phase of horizontal bipolarity; (3) the phase of vertical bipolarity with migration into the position of the granule layer, and (4) the assumption by the granule cell of its typical position in the second layer of the cortex.

The formation of the basket cells in the molecular layer depends upon a similar evolution of four phases: (1) The phase of germinal indifference; (2) the phase of horizontal bipolarity; (3) the phase of the formation of the young stellate cell, and (4) the phase of the formation of the terminal end-brushes of the axones.

It is still uncertain whether the cells of Purkinje and the stellate cells of Golgi develop from neuroblasts in the mantle layer or whether they also migrate downward from the ependymal cells of the rhombic lip. That many of the cells in the mantle layer take part in the formation of the cortex there can be no doubt.

In embryos at the end of the third month, the nucleus dentatus may be seen in the interior of the lateral lobes. The cells forming this nucleus have been derived from the cells of the mantle zone. Later, as the nucleus dentatus becomes sharply outlined, it takes on the convoluted form seen in the adult. The other medullary nuclei are derived in the same manner from the mantle layer.

CHAPTER XXVI

THE CEREBELLUM

ITS FUNCTIONAL SIGNIFICANCE

Experimental Evidence. Cerebellar functions have been matters of discussion for many years. Numerous investigators have devoted their attention to this problem, and the most important of their opinions concerning it are essential to an adequate conception of the organ. In the main, there is a surprising unanimity in these opinions, which, although varying much in detail, have a common keynote with regard to the functions of the cerebellum.

The earliest authoritative investigations are usually attributed to Flourens, who reported his notable experimental work on birds and mammals in 1842. His observations led him to believe that the regulation of locomotor acts in walking, running, leaping and flying, depends upon the cerebellum. Cuvier formulated this conception in the statement that "the integrity of the cerebellum is necessary to the proper regulation of locomotor movements."

Majendie who repeated the original experiments of Pourfur de Petit by cutting the cerebellar peduncles, concluded that the cerebellum is primarily the organ for equilibrium rather than for the coordination of locomotion, while Lussana and Lemoigne maintained that it is the center for muscular sense.

The conclusions of Flourens and Magendie found support in many subsequent investigations, especially by Serres, Hertwig, Foville and Desmoullin.

Vulpus and Philippeaux observed that destruction of the cerebellar connections in the fish produced disturbances similar to those described by Flourens in birds, and Goltz found that injuries to the cerebellum in frogs led to inexact motor control.

Weir Mitchell in his studies upon birds contributed a new observation to the record of experimental work upon the cerebellum. He noted that fatigue was a constant phenomenon following experimental operations, and concluded that the cerebellum was, among other things, the source of energy and muscular strength.

Ferrier considered the cerebellum an organ having to do with the maintenance of equilibrium, and this also was Stefani's interpretation. Nothnagel recognized certain differences in function between the vermis and hemispheres, since it was destruction of the former only that led to motor disturbances. The hemispheres were not concerned in the control of locomotion.

To Luciani we are indebted for the important contribution in which

he critically reviewed previous work upon the cerebellum. Upon the basis of his own investigations on apes and dogs, he constructed the hypothesis that the cerebellum is an organ which provides a sthenic, tonic and static control for the muscles, and that defects in this control lead to what he termed *asthenia*, *atonia* and *astasia*, the clinical manifestation of the last being *ataxia*. These three major symptoms are known as the *triad of Luciani*, and have been generally accepted in connection with cerebellar disease.

André Thomas demonstrated the important fact that in experimental animals the symptoms were not all of the same character, but depended much upon the pathological factors which produced them. Thus he noticed symptoms of irritation due to stimulation by hemorrhage, or to the trauma of the operation, or perhaps to compression of a blood clot consequent upon the operative procedure. The second type of symptoms due to cerebellar experimental work was caused by destruction that gave rise to inhibitory defects, while the third class included changes due to substitution and compensation, which made their appearance after the lapse of considerable time following the operative disturbance.

André Thomas gave much attention to the peculiar symptoms known as *forced movements*, which appear in experimental animals as a result of partial destruction of the cerebellum. He called attention to the direction which these forced movements invariably take, especially after removal of one hemisphere. A dog operated upon in this manner, after recovering from the effects of the anesthetic, tends to roll over and over, rotating about his long axis in a direction always away from the sound side and toward the side of the operation. It was also shown that animals upon which the various cerebellar operations had been performed, although they were unable to maintain an upright position in standing or walking, if placed in water, could swim. This remarkable and contradictory condition was explained by the fact that the body under these circumstances was surrounded by a medium more tangible than the air, which because of its denser nature augmented the afferent impulses from the skin, muscles and joints, thus permitting the animal, while in the water, to compensate for much of its loss in muscle and cutaneous sensory impressions. André Thomas does not wholly agree with Luciani as to the *asthenia*, *astasia* and *atonia* resulting from cerebellar lesions, but believes that the organ is most concerned with equilibrium.

Versilov, as a result of his experiments, concluded that the cerebellum is an organ of equilibrium, that experimental defects in equilibrium depend upon *asthenia* and *ataxia*, that disturbances apparent in the tremor and pendular movements of the head and body are increased by attempts at volitional control, that removal of the cerebellum causes an increase in the deep reflexes, and that the cerebellar control is ipsilateral in the hemisphere and bilateral in the vermis.

Cerebellar Localization. The first extensive attempts at cerebellar localization were made by Bolk upon a large series of the lower animals. His method of approach to the problem, together with his conclusions, have already been summarized.

Experimental investigations to test Bolk's cerebellar localization were made by Van Rijnberk working in Luciani's laboratory. Van Rijnberk explored the cerebellar cortex by means of circumscribed extirpations of certain of the lobules. The results of his work confirmed Bolk's hypothesis and showed that the localization as outlined by that investigator was essentially correct. Van Rijnberk's conclusions are as follows:

1. Total or partial extirpation of the lobus simplex produces side to side oscillations of the head due to an asynergia in the muscles of the neck.
2. Complete extirpation of the crus primum produces bilateral disturbances in the fore limbs, which, in the first stages, appear as irritative symptoms with the assumption of characteristic positions likened by the author to the military salute. Later there occurs considerable asynergia in the movements of the limbs.
3. Extirpation of the crus secundum produces asynergia and asthenia in the muscles of the hind legs.

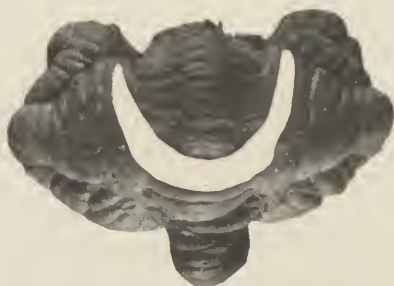


FIG. 338.—Extirpation of lobus simplex cerebelli in the dog (area in white), produces lateral oscillations of the head. (*Van Rijnberk.*)

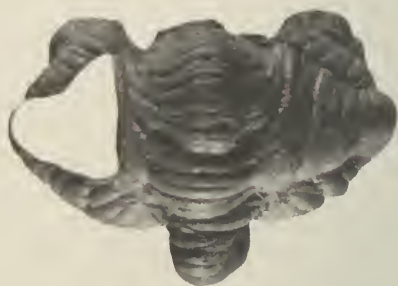


FIG. 339.—Extirpation of the left crus primum cerebelli in the dog (area in white), produces bilateral asynergia in fore limbs. (*Van Rijnberk.*)

4. Extirpation of both crura of the lobulus arciformis produces marked asynergia and asthenia in both fore and hind legs on the same side as the lesion.

5. Extirpation of the lobulus paramedianus causes rotation about the longitudinal axis of the body associated with the tendency to fall toward the operated side.

The symptoms in all cases gradually become less marked, and ultimately almost entirely disappear, owing, according to Luciani, to organic compensation.

The observations of Van Rijnberk have subsequently been confirmed in all their essential details by many investigators working upon dogs, monkeys and other animals. This is particularly true of the work of Rothmann, and of André Thomas and Durupt. All of these investigators point with emphasis to the fact that destruction of the cerebellar cortex does not give rise to paralysis, but does produce a disturbance in coordination of the muscles of the body.

Their investigations have carried cerebellar localization a step further

by showing that within the paired centers for the upper and lower extremities there are definite subsidiary centers for the direction of antagonistic muscles. Each subsidiary center for the extremities is related to a single segment or articulation of a limb, and controls the elaboration of the sthenic, tonic and static impulses distributed to a definite muscle group. An almost uniform observation, as a result of experimental work upon the cerebellum, is the gradual regression of the cerebellar symptoms in the course of time. This has been attributed either to an organic compensation by the uninjured parts of the cerebellum itself, or to an actual functional compensation by the volitional control of the cerebral cortex.

Experimental Evidence from Stimulation of the Cerebellar Cortex. The excitability of the cerebellar cortex to experimental stimulation has been the subject of much dispute. Versilov made extensive studies upon the cerebellum by means of different types of stimulation, using electrical, mechanical, chemical and thermal stimuli. His conclusions are as follows:

1. All the phenomena which result from stimulation of the cerebellum show that its function relates exclusively to the motor sphere.

2. The motor responses of the muscles of the neck, the trunk and the extremities, resemble in their general character the responses obtained as the result of stimulation of the cerebral cortex, being both tonic and clonic contraction of isolated muscle groups.

3. The relations of the cerebellum to movements of the body, of the neck, of the head and of the extremities, appear to be territorial, so that the right hemisphere of the cerebellum controls the right body half, and the left cerebellar hemisphere the left half of the body. The middle lobe likewise has a similar partition corresponding to the right and left halves of the body. The superior vermis stands in relation to the upper extremities, while the inferior vermis controls the lower extremities.

4. In addition to its relation to the muscles of the extremities and the trunk, the cerebellum has some participation in the innervation of the cutaneous muscles.

5. The movements of the eyeball are under the control of the cerebellum. Particular areas of the cerebellar cortex when stimulated give rise to several varieties of eye movements.

6. All of the eye movements appear to be synergized.

7. Nystagmic movements of the eyeballs form an almost constant phenomenon resulting from stimulation of the cerebellar cortex. The direction of this movement is variable, yet four chief movements may be differentiated, namely, horizontal, vertical, diagonal and rotatory.

8. Besides the usual movements of the eye as a result of stimulation of



FIG. 340.—Extirpation of the left crus secundum cerebelli in the dog (area in white), produces bilateral synergia in hind limbs. (*Van Rijnberk.*)

the cerebellar cortex, there are movements which result in protrusion and retraction of the eyeballs.

Stimulation of the cerebellar cortex also causes changes in the movements of the eyelids.

Prus also conducted experiments upon the cerebellum by means of various types of stimulation; his conclusions are summarized as follows:

1. The cortex of the cerebellum is excitable by electrical stimuli.
2. Excitability manifests itself in the form of tonic and clonic contractions in the muscles of the same side of the body.
3. Excitability of the cerebellar cortex is much influenced by the direction of the electric current. The longitudinal application of the electrodes in stimulating the neighborhood of the midline of the vermis brings about bilateral contractions.
4. Transverse stimulation brings about tonic contraction, while longitudinal stimulation produces clonic contraction.

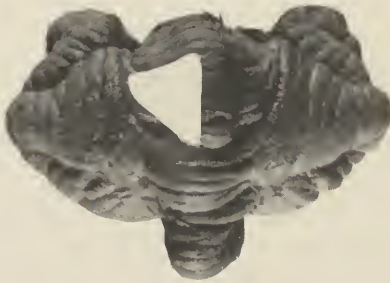


FIG. 341.—Electrical stimulation of the left half of the clivus cerebelli in the dog (area in white), produces movements in the left shoulder girdle and fore limb. (*Bechterew.*)

5. In the vermis, there are motor centers for the muscles of the body, of the eye and of the neck. In the anterior portion of the cerebellar hemispheres are centers for the fore limbs, and in the posterior portion centers for the hind limbs.

6. The dependence of the stimulation phenomenon upon the direction of the current is due to the arrangement of the Purkinje cells, the dendrites of which extend transversely to the long axis of the folium.

Bechterew, as a result of electrical stimulation of the cerebellar cortex, arrived at the following conclusions:

STIMULATION CONFINED TO THE VERMIS. 1. Stimulation of the left side of the pyramis at its cephalic extremity produces movements of the anterior extremity on the corresponding side.

2. Stimulation of the pyramis near the spinal cord results in movements of the posterior extremity on the corresponding side.

3. Stimulation of the entire left half of the pyramis occasions simultaneous movements of the anterior and posterior extremities on the same side.

4. Stimulation of the right side of the pyramis near its middle produces movements of the right anterior extremity.

5. Stimulation of the right side of the pyramis near the spinal cord produces movements of the right posterior extremity.

6. Stimulation of the entire right half of the pyramis produces movements of the anterior and posterior extremities of the corresponding side.

7. Stimulation of the cephalic portion of the pyramis near the midline produces movements of both anterior extremities.

8. Stimulation of the pyramis in the midline near the spinal cord produces movements in both legs.

9. Stimulation of the entire pyramis in the midline gives rise to simultaneous movements of the anterior and posterior extremities.

SIMULTANEOUS STIMULATION OF THE ANTERIOR PORTION OF THE CLIVUS AND THE POSTERIOR PORTION OF THE CULMEN. 1. Stimulation of the left anterior portion of the clivus and of the sulcus which separates it from the culmen, occasions movements of the left shoulder girdle and left anterior extremity.

2. Right-sided stimulation of the most anterior portion of the clivus and the fissure separating it from the culmen occasions movements of the right shoulder girdle and right anterior extremity.

3. Stimulation of the median part of the anterior portion of the clivus and its fissure occasions movements of the entire shoulder girdle, together with movements of both anterior extremities.



FIG. 342.—Electrical stimulation of the left half of the culmen cerebelli in the dog (area in white), produces deviation of head and eyes to left. (*Bechterew.*)



FIG. 343.—Electrical stimulation of the left half of pyramis cerebelli in the dog (area in white), produces movements of the left fore and hind limbs. (*Bechterew.*)

STIMULATION OF ONE-HALF OF THE CLIVUS AND CULMEN. 1. Stimulation of the indicated portion of the left half of the culmen and clivus brought out during the passage of the current a deviation of the eyes and of the head toward the left. Increase of the stimulation caused a movement of the eyes to the right, followed also by a movement of the head in the same direction.

2. Stimulation of the indicated portion of the right side of the clivus and culmen caused a deviation of the eyes and the head to the right; after an increase of the current the eyes and head were turned to the left.

The evidence derived from stimulation of the cerebellar cortex at the hands of several investigators seems to be conclusive, not only as to its experimental excitability, but also with reference to the presence of localized functional areas within it.

Clinical Experimentation and Clinical Evidence. Pathological conditions of the cerebellum have furnished much useful data concerning the functions of the organ, especially those due to circumscribed lesions such as tumor, abscess or cyst. Rothmann, André Thomas and Durupt, Babinski

and Tournay, have contributed by this means to the theory of cortical localization in the human cerebellum, which more recently has been elaborated by the clinico-pathological and experimental work on human subjects by Robert Bárány. As the result of a large series of observations, Bárány has evolved certain clinical tests by means of which it is possible to localize circumscribed cerebellar lesions with a marked degree of accuracy. One of the tests is especially pertinent in clinical localization:

BÁRÁNY'S INDEX OR POINTING TEST. During this test the patient's eyes are blindfolded. With his elbow on a firm support he is instructed to touch with his index finger an object held in front of him. This he does repeatedly, first in several vertical planes, then in horizontal planes. If there is a constant tendency toward deviation from the plane of movement, its direction is noted. By a slight modification of the procedure, it is possible to test each of the limb segments in all positions of rotation, pronation and supination.

These tests are performed in two ways; first, *without* previously induced nystagmus, either by rotation or by the method of introducing water into the external ear; second, *after* inducing artificial nystagmus by the means mentioned. The normal subject presents the following reactions:

1. Without induced nystagmus the tests in question are correctly performed, there being no deviation.

2. After artificially induced nystagmus, a deviation is noted in the direction corresponding to the slow movement of the nystagmus. This is termed by Bárány the *reaction deviation*.

If there be a cerebellar lesion present, certain variations of the above reactions will be observed:

First, when tested without induced nystagmus, a definite deviation will occasionally be noted. This is what Bárány termed *spontaneous deviation*.

Second, after inducing artificial nystagmus, there is an absence of the normal deviation reaction.

This test has proved most useful in diagnosis. The deviation which is observed during these tests serves to indicate the side of the cerebellar lesion. Bárány, employing this means of investigation, which he supplemented by much clinico-pathological material, and by experimental inhibition of the cerebellar cortex in patients during operation by rapid artificial cooling of the surface, has identified definite areas associated with the special muscular actions. His conclusions are summarized as follows:

1. There exists an exact localization of function in the cortex of the cerebellum.

2. The centers for the extremities are situated in circumscribed areas of the cortex of the hemispheres.

3. These centers correspond to those postulated by Bolk and experimental researches of other authorities.

4. The centers for the right and left extremities are situated respectively in the right and left superior and inferior semilunar and digastric lobules.

5. Within these centers the representation of the limb musculature is

spatially determined by the action of its various functional groups and by their position in the limb. Thus, within the arm center, other subsidiary centers are recognized governing movements of the limb in the horizontal plane, in the sagittal plane, in rotation, pronation and supination. In each subsidiary center the more minute arrangement of functional areas is in accordance with the movable segments of the limbs.

6. The sudden destruction of a center in the cerebellar cortex concerned in movements of the limb in a given direction, as for example to the right, results in the production of spontaneous deviation in the opposite direction, that is, to the left. This spontaneous deviation disappears in time, either through compensatory action of the cerebral cortex or of the cerebellum itself.

7. The principal centers of direction which have been determined are localized as follows:

(a) A center for the control of the musculature concerned in the movements of the right arm downward is situated in the median portion of the right inferior and superior semilunar lobules.

(b) A center for the control of the muscles concerned in abduction of the right arm is situated in the lateral angle of the hemisphere in the right superior and inferior semilunar lobules.

(c) A center for the control of the musculature concerned in abduction of the right hand is situated in the anterior part of the right digastric lobule.

(d) A center for the control of the musculature adducting the right arm is situated caudad and laterad from the preceding center in the right digastric lobule.

(e) Still more laterad and caudad on the right side is situated a center for the control of the musculature adducting the right thigh.

The left hemisphere contains a similar arrangement of centers for the extremities of the left side of the body.

The clinical evidence thus far adduced seems to be in accord with the theory of cerebellar localization originally formulated by Bolk. Bárány's localizations in the human cerebellar cortex have yet to be confirmed in detail, but the importance of his work cannot be overestimated.

Synergia and Synergic Movements. The recognition of the cerebellum as an organ essential to motor control is the principal feature in the conclusions of all observers. Babinski expresses this consensus of opinion when he says that "every form of active muscular exertion necessitates the simultaneous cooperation of immense assemblies of synergic movements throughout the body to secure steadiness and maintain general equilibrium, and on the hypothesis that the cerebellum is the center of these unconscious adjustments, we would expect the cerebellum to be developed in proportion to the variety and complexity of the motor activities of which the animal is capable. The facts of comparative anatomy and development are entirely in harmony with this hypothesis."

The explanation of cerebellar disturbances given in Luciani's triad of asthenia, atonia and astasia, although affording a generalized conception of

the nature of these defects, is scarcely analytical enough to meet the demands of clinical experience.

Mills and Weisenburg, in consequence, have maintained that Luciani's triad requires a new interpretation. According to their view, *synergia* is the fundamental function of the cerebellum. Their clinical studies convince them that *asynergia* is the fundamental symptom of cerebellar disease. Certain symptomatic modifications of this disturbance appear as *dysmetria* (improper measurement of movements), *adiadochokinesis* (inability to perform succession movements) and *tremor*. *Asthenia* and *atonia* are secondary effects of *asynergia*.

Definition of Synergia. Synergia, according to Mills and Weisenburg, is the power or faculty by which movements more or less complex but functionally definite, are associated in special acts. In a broad sense it is a motor association, this association being carried out in movements of different parts of the same limb or in synchronous movements of the limbs, of the limbs and the head, or of the trunk, limbs and head together.

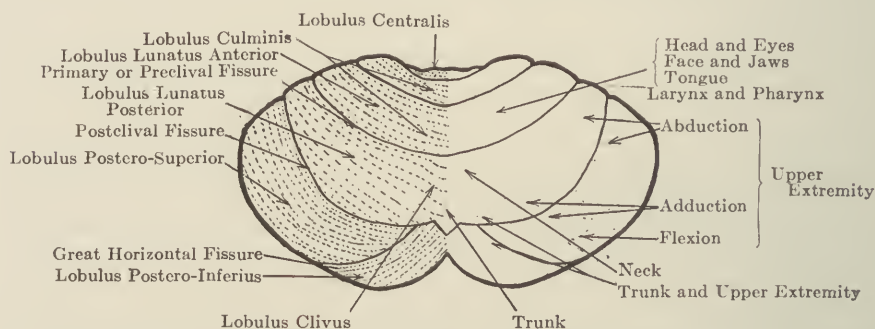


FIG. 344.—Scheme of localization in the human cerebellum; zones and centers of the superior surface of the cerebellum, according to Mills and Weisenburg.

THE CEREBELLAR GAIT—TRUNKAL ASYNERGIA. Mills and Weisenburg, in addition to their clinico-pathological studies, employed the cinematograph to investigate cerebellar symptomatology. By this means they were enabled to study the gait in patients suffering from cerebellar diseases, the disturbances of which in the majority of cases were chiefly trunkal. The trunk may be carried either backward or forward, forward and to one side, or simply to one side alone. This inclination may be total or partial. Every attempt on the part of the patient to walk causes the trunk to lean backward, forward or to one side. It is impossible for him to stand for any length of time in the erect position. He may be able for a short time to stand or walk either with the trunk erect or leaning in some direction, but he is soon likely to lurch forward, backward or to one side. In such cases, *asynergia* of the trunk is predominant and forms the most impressive part of the disturbance. The legs seem to act as props; the trunk leads, and whichever way it goes the legs follow. If the trunk leans forward and to the left, the swing of the left leg is shorter than that of the right, or if the trunk goes forward and to the

right, the swing of the right leg is less than that of the left, and the legs finally accommodate themselves to the movements of the trunk.

ASYNERGIA IN THE PELVIC AND SHOULDER GIRDLE MUSCLES. The observations of Mills and Weisenburg concerning the muscles of the pelvic and shoulder girdles in locomotion are especially instructive. In certain cases the asynergia is just as marked in the shoulder as in the pelvic girdle. When the asynergia is most marked in the pelvic girdle, the legs are held farther apart, the arms nearly always are outstretched and semiflexed at the elbows. When the asynergia is shown in the pelvic movements alone, the trunk is held rigidly erect and the legs are moved forward from the pelvis, giving the impression that the trunk follows the legs. In the extreme pelvic girdle cases, it is difficult for the patient to walk without assistance, and when assisted, the trunk is rigid and the legs are thrown out in any direction. The cerebellar gait is often described as a drunken, reeling or titubating gait. It is, however, not like that of a drunken man who reels in any direction, but does this largely because of his cerebral incapacity. A slightly intoxi-

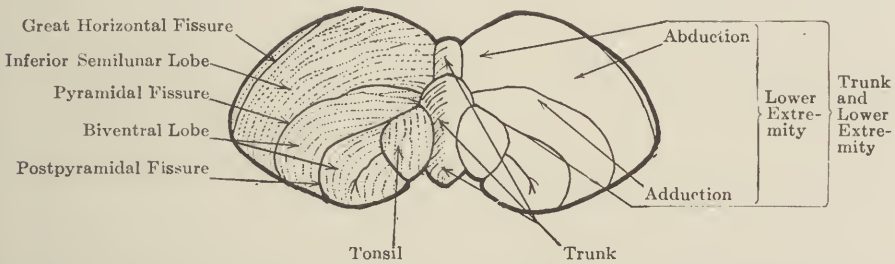


FIG. 345.—Scheme of localization in the human cerebellum; zones and centers of the inferior surface of the cerebellum, according to Mills and Weisenburg.

cated person reels forward or to one side, while one who is much intoxicated is unable to stand and any attempt to do so brings about a collapse of the body. There is no attempt on the part of the drunken man to hold his arm outstretched for protection, whereas the cerebellar patient is always careful as to the manner in which he walks, for knowing his own tendency to stagger, he makes efforts to obviate this by assuming corrective positions. In other words, he calls upon his cerebrum for compensations which are largely out of commission in the intoxicated person.

ASYNERGIA IN MOVEMENTS NOT CONCERNED IN EQUILIBRIUM—DYSMETRIA. Asynergia also appears in movements of the limbs not directly concerned in the maintenance of equilibrium. In performing the finger to nose test, the act may be finally executed by the patient, but the circle described in the entire movement is greater than normal, and the component movements are quicker than usual. This defect is due to improper measuring of the movements, or dysmetria. The more marked the dysmetria, the greater the tendency for the sweep of the arm to be inward due to the involvement of the shoulder girdle. Evidence of dysmetria in the legs obtained by the heel to knee tests is seen first in overflexion of the thigh on the abdomen so that the heel overshoots the desired mark.

ASYNERGIC SPEECH DEFECTS. Asynergia may likewise affect speech, giving rise to involvement of the tongue, face and laryngeal movements. Speech becomes jerky and irregular. The jaw muscles, the muscles of the pharynx, and the muscles producing movements of the head may be similarly affected.

OCULOMOTOR ASYNERGIA. The muscles producing movements of the eyeballs are frequently involved. As a result of such disturbance, the eyes are never at rest; they move upward or downward or to either side, or may combine all of these movements with a nodding of the head. No two successive movements of the eyeballs are quite alike in cerebellar nystagmus.

Cerebellar Localization on the Basis of Clinico-Pathological Evidence. Mills and Weisenburg arrived at the conclusion that there is a definite functional localization in the cerebellum.

The culmen and the anterior lunate lobules are centers for synergic control of the head and eyes, the face and jaws, palate, larynx and pharynx.

The clivus and the entire inferior vermis of the cerebellum control trunkal movements.

The posterior lunate lobule is the center for the upper extremity, its most lateral portion having control of abduction, its more mesial portion of adduction, and its intervening areas of extension of a limb.

The inferior portion of the cerebellar hemisphere controls the lower extremity, the lobulus postero-inferior having control of abduction, the lobulus biventralis controlling adduction.

The rôle of the cerebellum is best exemplified in the performance of such complex movements as those of fencing, of boxing or in playing tennis. In the human cerebellum there are centers for simple synergic movements as well as zones for complex synergic performances. It is important to recognize that each simple synergic movement has its special cortical representation in the cerebellum.

Synergia as Comprehending Cerebellar Functions. The accumulated evidence obtained from the extensive investigation of the cerebellar problem seems at length to be harmonized in the conception that *synergia* is the principal function of the cerebellum. This determines a common ground upon which all may stand, since the term synergia furnishes a definition of the functional attributes of the cerebellum in which the many differences in view-point may finally be conciliated.

Analysis of Synergia into its Component Factors. Although it is not difficult to appreciate the general significance of synergia, its more intimate nature requires the further elucidation to be obtained from the analysis of its exact anatomical and physiological factors. Recent work by Adrian Lambert and Tilney has been carried on to this end. The material studied consisted of normal individuals and patients suffering from cerebellar disease. The method of investigation was a combination of *kymographic analysis with bradykinetic analysis* in which slow motion pictures were employed. The photographic rate of these ultra-rapid motion pictures was 160 to the second instead of the usual cinematographic rate

of 16 to the second. This method offered an opportunity to study normal and disturbed motion by means of an actual graphic record with a visual analysis of them by the slow motion pictures. As a result of these investigations, it was concluded that *synergia is dependent upon two factors*:

1. *The establishment and maintenance of synergic muscular units throughout the body, and,*
2. *The establishment and maintenance of coordination between the synergic units in the performance of complex acts.*

THE SYNERGIC UNIT. The conception of the synergic muscular unit was obtained by kymographic studies, which showed that throughout the entire body the muscles are arranged in unit groups, each unit consisting of agonist and antagonist. The teaching, however, that these groups operate as antagonists has been misleading. They are antagonists only in the sense of their anatomical position. Physiologically they are synergists, and carry on their work by a mutually coordinated cooperation. If, for example, a single antagonistic group be considered, such as the flexors and extensors of the wrist upon the forearm, it is apparent from their position on the dorsal and ventral surface of the forearm that these muscles are antagonistic. When, however, their action is recorded by means of kymographic tracings, showing the movement of the flexors and extensors simultaneously, it at once becomes evident that they no longer may be regarded as antagonists but are in fact *synergists*. In flexion of the wrist, although the flexor curve rises to a higher point, it is followed throughout its entire course by a corresponding extensor curve, and similarly, during extension, although the extensor curve is the greater, it is none the less certainly followed by a corresponding flexor curve during its entire course. It thus appears that the flexors and extensors of the wrist are in reality a synergic unit, and that when one acts the other acts with it.

The Dominant and Check Elements in the Synergic Unit. In this unit two factors may be recognized, first, the dominant element which determines the direction of the movement, and second, the check element which works constantly with the dominant in order to provide the necessary limitation, so that the resultant movement may at no time be excessive but always exactly adapted to the purpose in hand. During flexion or extension of the wrist, there is a constant relation between dominant and check elements. When the proper ratio between these two elements is lost, the synergic unit is then deprived of its even mode of operation and the movements in the parts become irregular. Extension becomes excessive, because the flexor check element is not sufficient to meet it. Over correction on the part of the flexors is therefore required, which in turn has an inadequate extensor check. This dissociation of the dominant and check elements leads to a series of irregular oscillations, constituting the clinical symptom of *ataxia* which is based upon a physiological disturbance of the muscles. What is true of this simple group of muscles in the forearm is true of all the muscle groups in the body.

Simple Synergia. Every agonist has its antagonist, and the two together constitute a synergic unit. There are synergic units in the hand, in the forearm, in the arm, in the shoulder girdle, in the trunk and neck, in the tongue and larynx, in the masticatory musculature and in the lower extremities. Each of these synergic units must be maintained in its proper relation in order that the volitional acts calling upon these groups of muscles may be carried on in their proper manner. When the proper relation between them exists, the muscles are in a condition of eusynergia, but when this relation is disturbed, defects in motion appear which represent a state of asynergia.

Integrative Synergia. The establishment and maintenance of co-ordination between the various synergic units which enter into the performance of complex acts are important features in the mechanism of synergic control. The simple act of flexion and extension of the wrist requires but a single synergic unit. Other acts, in themselves not extremely complex, require the combination of several synergic units, such for example, as lifting the hand to take a glass of water from the table, raising it to the lips, drinking and putting the glass again upon the table. This motor performance requires a coordinated operation of synergic units in the hand, forearm, arm and shoulder girdle. It necessitates the proper correlation of these units one with the other. They must act together and maintain the proper relations in the phases, rate, force and extent of the muscular contractions involved.

Kinetic and Akinetic Phases of the Synergic Units. During such an act each of the synergic units involved in the performance passes through two phases. At one instance, it will contract to produce motion in the part, such as the contraction of the extensors of the fingers, opening the hand preparatory to grasping the glass, or the closure of the fingers about the glass. Immediately upon these acts having been accomplished, the fingers remain flexed and motionless, although the muscles of the fingers are in active contraction. This illustrates the two phases through which all synergic units are constantly passing during volitional activity. The first, that which produces motion, is the *kinetic phase*; the second, that which produces a fixed position under active contraction of the muscles, is the *akinetic phase*. These two phases of each synergic unit must be correlated in the time of their action, so that, for example, the fingers shall not close prematurely before the glass is grasped and so that they shall pass at the proper time into the akinetic phase in order to retain the glass in the hand. The synergic unit must be correlated also in the force applied during both the kinetic and akinetic phases. This must be adequate to the purpose of the act. The extent of the muscular contraction must likewise be regulated so that it fulfils the purpose of the act; otherwise the distances through which the part moves will be incorrect, with the resulting symptoms of *dysmetria*, that is, overmeasuring or improper measuring of the distances concerned in the muscular performance.

If in this relatively simple volitional act, it is necessary to coordinate the number of synergic units mentioned, how much more complex is the

synergia which brings into action the greater number of volitional performances, as in running or leaping, in playing tennis or base-ball, where all the synergic units in the body come into play and must be maintained in their proper relations. The maintenance of the synergic units in proper coordination during the performance of complex acts may be called *composite or integrative synergia*.

It is evident, however, that the basis of all of these synergized movements is the synergic unit and that disturbances in it will lead to marked disorders of motion either in the entire body or in certain limited parts of it.

Types of Integrative Asynergia. Several types of integrative asynergia may be recognized depending upon the distribution of the disturbance. Asynergia may be confined to the extremities, either to the arms or legs or to one extremity. This is *appendicular asynergia*. On the other hand, the defects in the synergic units may involve the axial musculature and the muscles of the trunk. This is *axial or trunkal asynergia*. A third type of asynergia affects both the extremities and the trunk simultaneously. This is *axio-appendicular asynergia*.

Synergia in the Light of Cerebellar Histology. An interesting light is shed upon this conception of synergia by the histology of the cerebellum. It is possible that provision is made in the histological connections of the Purkinje cells for the varieties of synergic control which have been recognized in the types of asynergia just described. It seems fair to presume that the *climbing fibers* which confine themselves to the trunk of the dendrites of single Purkinje cells have to do with the regulation of single synergic units. The *basket fibers* make possible the grouping together of collections of Purkinje cells, whose purpose it may be to mediate the more complicated synergic control for the operation of groups of synergic units, while the connection accomplished by means of the *granule cell* brings about an assemblage of vast numbers of Purkinje cells in control of large numbers of synergic units, perhaps corresponding to the entire musculature of the body. In this sense, while it is undoubtedly the case that there is definite localization within the cerebellar cortex, such localization is by no means so discrete as that seen in the cerebral cortex. In fact, it may be assumed that the cerebral cortex in its relation to voluntary motion has the supervision of the motor purpose as its chief object, while the synergic control of the cerebellum has as its primary function the regulation of the muscular patterns necessary for performance of that purpose.

It is not surprising, therefore, that in the efforts to determine an exact functional localization in the cerebellar cortex, so much more difficulty has been experienced than has been the case in the cerebral cortex. Cerebellar localization implies much more the patterns of movements than the parts employed. It is exact for circumscribed or limited acts, but it is diffuse and probably without definite limits for the great majority of volitional performances carried on by the muscles.

Summary Concerning the Functions of the Cerebellum. 1. The fundamental cerebellar function is synergia, which depends upon the proper relations of the synergic units of the body.

2. A synergic unit consists of a muscular group of anatomical antagonists whose physiological action is represented by the mutual synergism in a dominant and check element. The entire musculature of the body is divided into synergic units.

3. Simple synergia depends upon the proper correlation of single synergic units.

4. Integrative synergia depends on the proper correlation of many groups of synergic units.

5. Disturbances of simple or integrative synergia lead to the clinical phenomenon of *asynergia* or *ataxia which is the essential cerebellar symptom*.

6. Asthenia and atonia are symptoms secondary to asynergia.

7. The synergic control of the cerebellum is essentially ipsilateral, that is, for muscles of the same side of the body; but axial and trunkal muscles are under a bilaterally dependent control, both halves of the cerebellum being active in the regulation of their movements.

8. The synergic control of the appendicular muscles is both bilaterally dependent and unilaterally independent, the unilateral independence being more prominent in the arms than in the legs.

9. The localization of definite areas in the cerebellum for the control of the several parts of the body is much more diffuse than is the case in the cerebral cortex, since the cerebellum regulates the entire motor pattern of the act, while the motor cortex of the cerebrum controls its purpose.

10. The superior and inferior vermis control the synergic action of the axial and trunkal muscles.

11. The superior vermis controls the movements of the eyes, neck, jaws, face, tongue, larynx and pharynx.

12. The inferior vermis controls the muscles of the trunk, and also acts in control of the bilaterally dependent movements of the extremities, that is, those movements of the limbs in which the extremities of one side act synchronously with those of the other side, as in walking.

13. The cerebellar hemispheres control the synergic action of the extremities in bilaterally independent acts, as for example, in the movements of one arm alone.

14. There may be areas which regulate adduction, abduction, flexion and extension as such, but these are to be regarded as parts of more comprehensive regions controlling movements of the extremities in all planes produced by the action of the synergic units.

CHAPTER XXVII

THE CEREBELLUM

THE PRINCIPAL CEREBELLAR SYNDROME AND ITS VARIATIONS

The Cerebellar Syndrome. The clinical records of diseases affecting the cerebellum comprise an extensive assortment of symptoms attributed to defects in this organ. Many of these symptoms are, in fact, extracerebellar and not in the strict sense part of the *cerebellar syndrome*. Cases in which the lesion is limited to the cerebellum itself, although relatively rare, afford the best clinical opportunity of investigating the nature of disturbed functions due to intrinsic cerebellar disorders. The following case offers a suitable clinical example of this kind:

HISTORY. The patient, a man forty-one years of age, unmarried and without occupation, complained of a severe motor disturbance which rendered him incapable of securing employment or of earning his living. He was dependent upon an unmarried sister, who for many years had endeavored to find some means of relief for her brother.

His disease first manifested itself in infancy. He was unusually late in sitting up and standing. He did not learn to walk until he was five years old. His earliest attempts to move his hands and arms, to sit up or to rise to a standing position, were attended by irregular swinging movements of the arms, legs, head and trunk. In his first attempt to walk he could not take more than two or three steps without falling, and he never learned to run without losing his balance.

His speech was at first slurring and unintelligible, except to his sister. Ultimately it became clearer, but was jerky and irregular. He was unable to use his hands in any act which required steadiness and precision, because on making the attempt his arms would begin to oscillate in such a way that he could not control them.

Mentally, the patient was alert and normally active. His education had been neglected, largely because it was impossible for him to attend public school on account of his motor disorder, and also because the family did not possess the means to provide private instruction. For what learning he had acquired he was indebted to the patient assistance of his sister, who had taught him until he could read in a somewhat slow and hesitating fashion. This was the extent of his book-learning. In the common knowledge of his walk of life he was not below the average, although he had never been able to associate with other men or participate in their usual activities.

His motor disabilities had occasioned many falls and bruises, as well as numerous unpleasant experiences. It not infrequently occurred that his reeling gait and general unsteady appearance led to his arrest on the charge

of intoxication, and the fact that his "intoxicated" state was persistent, showing none of the usual signs of improvement at the proper time, puzzled the officials. While in charge of the authorities, it was admittedly impossible for him to obtain intoxicants, yet the signs of intoxication continued unchanged. The case always proved too much for police intelligence and the patient was finally discharged with the advice to see a physician.

Often he applied for employment, but because of his unsteadiness of speech and manner he was usually rejected. Several times, however, he managed to obtain a position as one of a large group of laborers, but always with the same result. He could not do the work, or else in his vain attempts he would fall and injure himself.

His general health was good. He complained of no pain or other distress. So far as he knew, with the exception of his muscular unsteadiness, his functions were all normal.

The family history of the patient contained no record of a similar condition in any of the direct or collateral branches of his family. His sister, his only living relative, was a normally developed and capable woman who gave no evidence of disturbance which in any way resembled that from which the patient suffered.

EXAMINATION. At the time of the examination, made in his forty-first year, he appeared upon inspection to be a man fairly well nourished and evidently a little older than his given age. He was six feet one and one-half inches tall; his weight was good. He answered questions intelligently, was mentally alert and cooperative. The neurological examination made on this occasion showed the following facts:

The Somatic Motor Component. This component showed that the *idiodynamic control*, as well as the *tonic control* of the muscles, was normal. The *reflex control* showed but a single departure from the normal. Upon taking the knee-jerk, with the patient sitting in such a way that both legs hung over the edge of a table, the percussion on the patellar tendon caused an active response, in which the leg oscillated seven or eight times backward and forward before coming to rest. All of the other deep reflexes were normal in their activity and equal on the two sides. There were no pathological reflexes, and the superficial reflexes, including the upper and lower lateral abdominals and the cremasterics on both sides, were present and active. There was no demonstrable change in the tone of the muscles in any part of the body.

The *volitional control* of the muscles was normal on both sides, and there was no appreciable decrease in the strength of any muscle group. Paralysis and asthenia as a result of the tests made were found to be absent.

Skilled performances were much impaired. This, however, was not explainable on the basis of any volitional motor disturbance, but rather in the distribution of the motor impulses by means of which the synergic control of the muscles was maintained.

The Gait. In testing locomotion, the four tests of Fournier were employed. The first, which requires the patient to rise from a chair and begin

to walk upon command, causes the sudden introduction of the equilibratory mechanism in locomotion. The patient upon rising from the sitting posture, at once began to stagger; as he continued to walk, the staggering became more pronounced. His gait soon became reeling like that of a drunken man, now to one side, now to the other.

Upon applying the second test of Fournier, that is, having the patient stop quickly on command while walking, he showed a typical disturbance in his equilibrium. In attempting to stop he lost his balance and fell.

The third test of Fournier, requiring the patient while walking to turn either to the right or to the left, also brought out marked disturbances of equilibrium.

The staggering gait corresponded to the locomotor disturbance described by Duchenne as *titubation*; but on further analysis it appeared that when walking his legs at times seemed to precede his body, which bent over backward or to one side, while at other times his trunk became flexed forward, in which case he would hasten his steps in order to keep his legs in line with the rest of his body. This was due to a decomposition of the synergized movements necessary to walking. Such decomposition of movement in walking is described by Babinski as *asynergia major*.

On attempting to run the patient invariably fell forward and to one side. In falling, his hands were automatically thrust out in front of the body to break the force of the fall. Tested on going up stairs, he presented the same tendency toward loss of balance.

In attempting to rise after a fall he assumed a position upon hands and knees and, while trying to get upon his hands and feet his body would sway from one side to the other, often resulting in a complete loss of balance. The lack of synergic control in his trunk muscles was pronounced, and his trunkal asynergia in all types of locomotion, whether upon his feet or when attempting to creep upon hands and knees, was one of his most prominent symptoms.

Station. In testing his station, he showed difficulty in standing with his feet close together whether his eyes were open or closed. In many cases of ataxia due to other than cerebellar conditions, it is a rule that the patient can manage to stand better with the eyes open than when closed. This is due to the fact that the visual impulses augment spatial orientation to such a degree that they make partial amends for these defects in muscle, joint, tendon and bone sensibility. In cerebellar lesions, however, it makes slight difference whether the eyes are open or closed, since the visual impulses compensate but little. In standing, the patient always assumed a position with his feet far apart, but even under these conditions his body swayed from side to side or backward and forward in an irregular manner.

On examining his synergic control in acts not directly associated with equilibrium, such as the finger to nose test, the hand and finger on approaching the nose presented several irregular oscillations which gradually increased toward the end of the act. The finger was finally placed either in the eye, upon the cheek or on the chin. The oscillations in the upper extremity during this

test were due to a lack of proper balance between the synergic units of the arm. It was impossible for the patient to perform this act correctly, regardless of the number of times it was repeated. Tests to demonstrate the synergic control of the lower extremities developed similar results.

Pass-Pointing. The attempt to touch a fixed point in any position in front of the patient with the tip of the finger consistently resulted in failure. This was the *spontaneous deviation of Barany*, which was not affected in any way by the production of artificial nystagmus.

All of these defects in synergic control were attributed to dissociation of the synergic units in the arms and legs which are necessary to the performance of the given acts.

The patient also showed marked defects in the integrative synergy of all movements of the trunk and extremities. He was examined by five tests devised by Babinski to demonstrate *asynergia minor*. These tests gave the following results:

1. *Leg Elevation Test.* The patient, in a supine position, was instructed to elevate the right leg. In doing so he began by flexing the thigh at the hip and finally extended the leg upon the thigh, resolving the act into its two component movements instead of performing it in one act, as is normal. This test was repeated with similar results in the left leg.

2. *Sitting up Test.* The patient, in a supine position, was instructed to sit up. In complying, flexion of the body began before flexion in the legs. Normally these two acts are carried on simultaneously but in this patient there was a dissociation of the components of the act resulting in actual decomposition of the movement.

3. *Foot Test.* The patient, while seated in a chair, was instructed to touch the hand of the examiner with his toes. This resulted in a series of irregular oscillations during which flexion of the thigh began before extension of the leg and foot, thus resolving the movement into its component parts. Both legs gave the same results.

4. *Kneeling Test.* The patient, standing beside a chair with his hands grasping the back of it, was instructed to place his knee on the chair. This he did first by flexing the thigh on the hip and then beginning flexion of the leg upon the thigh, thus dissociating the two movements. Both legs showed the same defects.

5. *Leaning Test.* The patient, in a standing position, was instructed to lean backward as far as possible. He was assured that he would not be permitted to fall. In leaning backward, extension of the spinal column was carried to a fair degree but the patient soon lost balance and would have fallen if he had not been supported. There were no associated movements in the legs in this act. Normally, when a patient leans backward as far as possible, in order to compensate for the disturbance in the center of equilibrium in the body, the legs are flexed at the knees. The two acts of extending the spine and flexing the lower extremities are essential to the maintenance of balance, but in this patient there was an evident decomposition of the two movements.

These tests furnish clinical evidence that the acts entering into any volun-

tary performance may be decomposed into their several component movements, thus giving rise to a lack of integrative synergia, which is one of the most prominent of cerebellar symptoms.

Dysmetria. In the performance of all skilled acts, it was found that the patient manifested a defective judgment in the distance, force and time of muscular contraction to such a degree that the accomplishment of the purpose was often defeated. His movements were executed without the proper measurement in time, distance, rate and force in action. The initial impulse was either too strong, the movement too rapid or else tardily executed. This motor disturbance has been called *dysmetria* by André Thomas. In three tests for dysmetria the patient showed the defect to a marked degree:

1. *Test of Grasping.* The patient was directed to lift his hand and grasp a glass of water on the table. The movement upward carried his hand well above the table. The fingers of the hand were opened before they needed to be. The hand came into contact with the glass so forcibly as to knock it over. The patient made several unsuccessful attempts to grasp the glass. This test showed that he had no proper measurement in the muscular activities necessary to grasp the glass.

2. *Test of Reversal of the Hands.* The patient was instructed to hold both arms extended in front of him so that the palms of the hands were turned upward. He was then instructed to turn the palms down with as rapid a motion as he could. This resulted in a pronation carrying the palmar surfaces of the hands into a position oblique to the ground, in other words, over-pronation.

3. *Heel to Knee Test.* The patient, in a recumbent position, was instructed to touch an object placed upon his right patella with the heel of his left foot. On the first attempt, the left heel was carried well up on the thigh, while on the second, it touched below the knee. The same disturbance was noted in the right leg.

Adiadochokinesis (*a* = primitive; *diadocho* = succession; *kinesis* = movement). This is a symptom of cerebellar disease described by Babinski as a failure in the ability to produce succession movements. The patient was instructed rapidly to flex and extend the forearm upon the arm, but was unable to do so except in an awkward and irregular manner.

Rebound Phenomenon of Holmes. In testing the strength of the upper and lower extremities, the patient manifested a significant symptom. When the examiner grasped the wrist firmly and attempted to draw the arm into extension against the patient's resistance, suddenly releasing the wrist, the patient's hand rebounded so that it struck his chest with considerable force. A similar rebound was also present in the lower extremity which would, if held flexed at the hip and knee by the patient against the examiner's attempts at extension, rebound forcibly when suddenly released and assume an extreme position of flexion. This rebound phenomenon of the extremities is another example of the dissociation between the synergic units, and demonstrates a failure in the check element.

Tremor. Every volitional movement of the patient was attended by a coarse, irregular tremor, which was increased when he directed his attention

to it or when he attempted to check it. The tremor was not apparent if the parts were not in action. It was also absent in sleep. It appeared upon the first attempt at voluntary movement of the arms, from which, if the act were continued, it spread to the neck and trunk. It was noticeable in the head and trunk when the patient was standing or sitting. No other abnormal involuntary movements were present, and no abnormal associated movements were discovered by the examination.

The Cranial Nerves. The motor divisions of several of the cranial nerves showed marked defects of innervation.

Nystagmus. The entire oculomotor mechanism (Nn. III, IV and VI) was defective. The eyes were in constant motion oscillating from side to side as well as upward and downward. The ocular movements, although irregular and jerky, were always conjugated. These movements were increased when the patient attempted to fix his gaze, and became especially active when he looked to the right or left. This disturbance had existed since childhood without appreciable change. It gave the impression of a complete dissociation in the synergic units of the eyeball, and is described as *irregular nystagmus*. The application of the caloric tests did not increase or in any way affect this nystagmus.

Disturbances of Cephalogyric Movement. Turning of the head either to the right or left and looking upward or downward were accompanied by a marked tremor in the muscles of the neck, causing the head to oscillate in an irregular manner.

Asynergic Speech. The patient's speech was scanning, interrupted and sometimes explosive. Often his articulation was that of a stutterer. His words were uttered syllabically or enunciated suddenly with unnecessary rapidity and force.

Asynergia in Mastication. When chewing, the muscles of mastication showed a similar asynergic defect; the lower jaw was often drawn upward with unnecessary force or depressed to an unnecessary degree.

The first and second cranial nerves were normal. There were no defects of vision other than those occasioned by the constant nystagmus. The optic discs and retinae were normal. There was no atrophy or pallor of either disc. There was no ocular palsy. The facial muscles were normal on both sides. There was no paralysis or disturbance of the soft palate, pharynx, larynx or tongue, other than those described in connection with articulation.

Bradykinetic Analysis. The motor disturbances of this patient were studied by means of slow motion pictures which brought out more clearly the fact that all of his motor defects were due to an asynergia resulting from dissociation of the synergic units.

The Somatic Sensory Component. All qualities of special sensibility and general somesthetic sensibility were tested with care and found to be normal. There was no alteration of discriminative, tactile, cutaneous, muscle, joint, or vibratory sense. Pain and temperature sensibility were likewise intact.

The Splanchnic Motor Component. With the exception of the trapezius and sterno-cleido-mastoid muscles, which showed asynergic defects already

described, there were no disorders attributable to the splanchnic motor component.

Tee Splanchnic Sensory Component. This component was normal.

Mental Status. Taking the patient's disadvantages into account, his mental condition was normal.

Laboratory Tests. These tests on the urine, blood and spinal fluid were negative.

INTERPRETATION AND ANATOMICAL ANALYSIS. From the history and duration of the disease, it is clear that the lesion is a congenital defect.

Evidence of the focus of the lesion is furnished by symptoms, all due to defects in synergic control, which indicate an involvement of the cerebellum. A review of these symptoms demonstrates that they are essentially asynergic in nature. They are motor disturbances, all of which may be explained as failures in the proper action of the synergic units of the body. Analyzed from this point of view, the symptoms align themselves as follows:

1. *The Pendular Knee Reflex.* This is due to an inadequate relation between the check and determinant elements in the synergic units which produce flexion and extension of the leg upon the thigh. Ordinarily the stimulation which causes the knee-jerk (percussion over the patellar tendon) stimulates the quadriceps extensor, the determinant element, and simultaneously the hamstring group which acts as the check element. Operating as a synergic unit, these two groups of muscles during the production of the knee-jerk serve to limit the motor reaction to one or two oscillations of the leg, even when the initial excursion is large. This is due to the mutual check action of the two muscle groups concerned in the reflex, a fact which has been demonstrated by kymographic record in the case of all normal reflexes. When the synergic unit for extension and flexion of the leg is dissociated, the mutual check action is lost and the leg swings like a pendulum. The pendular knee-jerk in this case did not result from decrease of muscle tone, since the latter showed no appreciable change.

All the other deep and superficial reflexes were normal.

2. *Disturbances in Equilibratory Synergic Control.* The disturbance in gait shown by the oscillations when the patient was standing with the feet together, or even when they were widely separated, was due to a dissociation of the synergic units necessary to the maintenance of the upright position. The disturbances of the gait in walking and running, in turning or going up and down stairs, were disturbances both in simple synergia and in the integrative synergia which resulted in decomposition of movement. The manner in which the body was inclined backward or forward in walking, thereby threatening to overthrow the proper center of equilibrium, an example of major asynergia, affords another instance of decomposition in synergic movements. The disturbances in rising from a sitting posture and creeping on the hands and knees also show defects in the synergic units as well as in the proper combination of these units to maintain equilibrium.

3. *Disturbances of Non-Equilibratory Synergic Control.* As shown in the asynergia minor of Babinski, all these disturbances illustrate a dissociation of

integrative synergic control. *Adiadochokinesis* is an illustration of a dissociation in synergic units, as is also *dysmetria* and the *rebound phenomenon of Holmes*.

4. *Tremor*. Tremor of the intention type is due to dissociation of synergic units, and in the strict sense, therefore, is *asynergia* rather than tremor.

5. *Nystagmus*. This symptom, as well as the disturbances of cephalogyric movements, is the result of disturbances in the synergic units controlling the eye movements and the movements of the head.

6. *Disturbances of Articulation*. These disturbances indicate a similar disorder in the speech mechanism, showing that both simple and integrative synergia have become defective. The speech disturbance is, therefore, due to *asynergia*.

7. *Disturbances of Mastication*. These disturbances illustrate the dissociation in the synergic units producing movements of the lower jaw.

By this analysis it is demonstrated that all of the motor symptoms were caused by defects in synergic control.

Evidence of circumscription of the lesion exempts all parts of the central nervous system except the cerebellum. The fact that *idiodynamic* and *tonic control* of the muscles is normal shows that the final common pathway is still effective. *Volitional control* is disturbed only in so far as the execution of volition is impaired by *asynergia*. The design and purpose of all motor acts are still intact, and the strength of the muscular contraction is normal. The *automatic associated control* shows no disturbance. All forms of sensibility are normal. This is a fact of chief importance, since it establishes a differential distinction between the ataxia due to improper sensory perception from the muscles and that which results from disease confined to the cerebellum.

DIAGNOSIS AND PATHOLOGY. This condition is due to a failure of development of the cerebellum.

NOMENCLATURE. This symptom-complex is known as the *syndrome of cerebellar agenesis*. It is also termed the *cerebellar syndrome of Nonne*.

VARIATIONS OF THE CEREBELLAR SYNDROME. The cerebellar syndrome in the strict sense is observed only in those conditions which cause intrinsic defects limited to the cerebellar structure. It appears in its purest form in *agenesis*, as in the case just described. Other pathological processes, however, may produce the cerebellar syndrome. It may be caused by *primary progressive cerebellar degeneration of Holmes*. This is a familial disorder occurring in adults between the ages of 30 and 40 and progressing slowly to a fatal termination. Clinically it is characterized by all the symptoms of the cerebellar syndrome.

Atrophy of the cerebellum, pons and olives, known as the *olivo-ponto-cerebellar atrophy of Thomas* may likewise show all the symptoms of the cerebellar syndrome.

Certain familial and sporadic involvements of the spino-cerebellar tracts may present many clinical features in common with the cerebellar syndrome; but these symptoms are invariably combined with others which establish the differential diagnosis. Involvement of the spino-cerebellar tracts is attended by disturbances in somatic sensibility, and frequently presents symptoms referable to disturbances of the upper motor neurone.

Extracerebellar Symptoms. Certain extracerebellar lesions which compromise the cerebellum, or intracerebellar lesions which compromise the neighboring structures outside of the cerebellum, produce associated extracerebellar symptoms. Some of these extracerebellar symptoms are due to pressure upon the cranial nerves connected with the medulla oblongata and the pons Varolii. Among these are:

Failure of vision with choked disc due to increased intracranial pressure.

Vertigo and labyrinthine nystagmus due to involvement of the vestibular division of the eighth nerve.

Tinnitus and deafness, due to the involvement of the cochlear division of the eighth nerve.

Facial paralysis, due to involvement of the seventh nerve.

Internal strabismus, due to involvement of the sixth nerve.

Dysesthesia, pain and paresthesia of the face, due to involvement of the fifth nerve.

Paralysis of the muscles of the jaw, due to involvement of the fifth nerve.

Anesthesia, pain and paralysis of the mouth and pharynx, due to involvement of the ninth nerve.

Laryngeal paralysis, respiratory and cardiac disturbances, due to involvement of the tenth nerve.

Spasm and paralysis of the tongue, due to involvement of the twelfth nerve.

A good illustration of extracerebellar symptoms is afforded by tumors of the cerebello-pontile angle, which in addition to involvement of the seventh and eighth nerves may extend forward to involve the roots of the fifth nerve, or backward to involve the root fibers of the glossopharyngeus and vagus nerves.

Other extracerebellar symptoms are due to pressure of masses either outside of the cerebellum but in the posterior fossa, or else contained within the cerebellum itself and pressing upon the medulla or pons Varolii. These symptoms may include:

Upper motor neurone paralysis of the leg and arm on the side opposite the lesion, due to compression of the pyramidal tract either in the medulla or in the pons.

Spasticity of the leg and arm, due to pressure upon the pyramidal tract.

Convulsions, usually of the unilateral type, or generalized, due to irritation of the pyramidal tract.

Alterations in the deep reflexes, either producing an increase in or causing the appearance of pathological reflexes, such as the Babinski and ankle clonus.

Disturbances in somesthetic sensibility, involving the muscle, joint, tactile, pain and temperature senses.

Disturbances in associated ocular movements, together with vasomotor, pupillary and secretory disturbances, due to involvement of the sympathetic system.

Loss of muscular power.

Paralysis or asthenia is not observed in cases due to intrinsic lesions of the cerebellum; such as acute parenchymatous degeneration, chronic atrophy or cerebellar agenesis.

Asthenia and atonia when present as a result of cerebellar disease are consequences of the involvement of an adjacent structure. These symptoms are most commonly observed in the more acute and fulminating affections of the cerebellum, such as tumor, abscess, gunshot wound and inflammation. It is questionable whether asthenia and atonia can be accounted primary symptoms in the cerebellar syndrome.

Cerebellar catalepsy, a condition in which the patient's limbs when placed in a certain position remain fixed for a considerable period of time, has been described as a cerebellar symptom by Babinski. This symptom, however, requires further observation before it may be attributed to defects in cerebellar function.

Dana has described a combination of symptoms due to cerebellar tumors. These symptoms develop suddenly as spasmodic seizures characterized by high pitched ringing in the ear, intense vertigo, a tendency to fall consistently either to the right or left, loss of consciousness and, in severe attacks, tonic spasms of the extensor muscles lasting from one to ten minutes.

SUMMARY. The essential clinical features of the cerebellar syndrome are:

1. Asynergia as manifested by
 - (a) Pendular knee-jerk.
 - (b) Asynergia major, which gives rise to the staggering gait caused by dissociation of synergic units of the trunk and extremities and the decomposition of synergic movements.
 - (c) Incoordination of station, due to the same causes.
 - (d) Asynergia minor, shown in the pass-pointing, finger to finger and finger to nose tests, and also in the five tests of Babinski for minor asynergia.
 - (e) Dysmetria, or improper measuring of extent, rate and force of volitional movements.
 - (f) Adiadochokinesis, a failure to produce succession movements.
 - (g) Rebound phenomenon of Holmes.
 - (h) Tremor on voluntary movement, which consists of irregular oscillations of the arms, legs and head.
 - (i) Irregular persistent nystagmus.
 - (j) Cephalogyric asynergia.
 - (k) Asynergic speech disturbances resulting in scanning, explosive and slurring articulation.

2. Absence of pronounced changes in the deep and superficial reflexes and in the tone of the muscles.

3. Absence of paralysis or actual loss of strength; *i.e.*, asthenia.

4. Absence of changes in general or special sensibility.

5. Absence of visceral disorders.

In brief, the symptoms of intrinsic cerebellar disease are confined exclusively to disturbances of the motor sphere, and affect only the equilibratory and non-equilibratory synergic control of the muscles.

CHAPTER XXVIII

THE MIDBRAIN

GENERAL SIGNIFICANCE, ANATOMY AND EMBRYOLOGY OF THE MESENCEPHALON

Divisions of the Mesencephalon. The mesencephalon (midbrain) is the division of the encephalon cranial to the pons Varolii. It is a small and constricted portion of the neuraxis situated between the rhombencephalon and the cerebrum. On this account it is sometimes referred to as the *isthmus encephali*. Like the hindbrain, the mesencephalon consists of three distinct parts:

1. The *tegmentum mesencephali*, representing the primitive segmental portion of the midbrain and comprising two encephalomeres.

2. The *basis mesencephali*, consisting of the cerebral peduncles, a late acquisition by the brain with the same significance as the pons Varolii.

3. The *tectum mesencephali*, a suprasegmental portion of the brain whose evolutionary history embodies one of the most interesting episodes in the development of the central nervous system.

In many lower vertebrates the midbrain is one of the largest portions of the neuraxis, but in man it has come to be the smallest and least conspicuous division of the brain. Unlike the cerebellum, it has failed to keep pace with the progress of evolution, and has gradually lost in prominence until it is obscured from view by the development of more recently acquired structures.

Evolutional Changes in the Midbrain. The progressive decrease in its size seems to indicate that the organ is recessive in its functional capacities. What are the reasons for this pronounced decline from its former importance among the major divisions of the nervous system? This question has a two-fold explanation, the first of which is found in the nature and the functions of the mesencephalon in its primitive form; the second appears in the progressive changes which have relieved the midbrain of its original functions and delegated its offices to more recently acquired parts of the brain.

The nervous system, in its earliest form, had for its purpose the immediate transformation of afferent sensory impulses into effector responses. This condition was present in the epoch of the reflex arc; all of the activities of life were then expressed as simple but immediate reflexes. Such reflex responses naturally imposed extreme limitations upon motor activity, which was not only confined to simple, restricted movements, but was also stereotyped and without variability. Motor activity of this kind provided a limited degree of adaptability to the animal's environment. The nervous system made provision for no broadly advantageous combinations of afferent impulses, and had it persisted in its original simple form,

the addition of new sensory receptors for vision, smell, taste and hearing would merely have resulted in the establishment of new and distinct systems of reflex arcs. Each new system would have been independent of all others and would have determined a series of reflex responses without bearing upon or correlation with the activity of any other reflex system. The advantage which might accrue from the correlation of visual and tactile impulses is evident at a glance. Obviously the clearest appreciation of the outside world is obtained from the blending of various types of general and special sensory impressions. It is upon the capacity for such correlation that the extent of individual experience and the even more important capabilities of adaptation to the environment depend.

Primitive Importance of the Midbrain in the Psycho-Associational Reflex. The development of an organ capable of forming such correlations determined the epoch of the psycho-associational reflex which, in the vertebrate, had its primitive centers in the mesencephalon. The midbrain was, therefore, a primordial organ for the correlation of sensory impulses. In the mesencephalon, three important sensory pathways primitively had their endings. These were the pathways for visual, auditory and somesthetic sensibility. Impulses re-



FIG. 346.—Diagrammatic representation of the mesencephalon (midbrain) in the vertebrate series. Dorsal view. Darkened area.

Petromyzon (lamprey) above. Scyllium canicula (dog-fish) below.

ceived by the midbrain from the eyes, from the ears, from the skin, muscles, joints and bones, were correlated in the interest of producing the most effectual motor responses. The more ample motor reactions resulting from this correlating process lost something in the rapidity of execution, because the synthesis of the several types of sensory impressions requires an appreciable lapse of time. On the other hand, they gained vastly in the precision, in the completeness, and in the efficiency of their accomplishment. The unisensory reflex depending upon stimulation received by way of one type of receptor only, manifests itself in a much simpler motor response than the plurisensory reflex, which is the result of a combination of stimuli received from several different types of receptors. The response, for example, to the point of a pin, applied to the surface of the hand when

the individual is not looking, is much more simple than the complex series of reactions when the individual sees the pin approach and make contact with the skin.

Relation of the Midbrain to Vision. The principal sensory pathway primitively ending in the midbrain comes from the retina of the eye by way of the optic tract. For this tract the mesencephalon originally formed the final end station upon which all of the processes of visual consciousness depended. This visual process includes an extensive number of visual associations and memories concerned with the size, shape and motion of objects, with their distance and direction from the body, with differing degrees of their illumination and differences of color.

Primitively the midbrain was the sole organ upon which the animal relied for the complex associations of visual consciousness. But the mesencephalon in its primitive form also receives impressions from the ear, muscles, tendons and joints. It makes provision for correlating these sensory impressions as such correlations are needed. For these reasons the primitive midbrain is a conspicuous division of the encephalon. The prominence which it has in the lower vertebrates is due particularly to the extreme development of its supra-

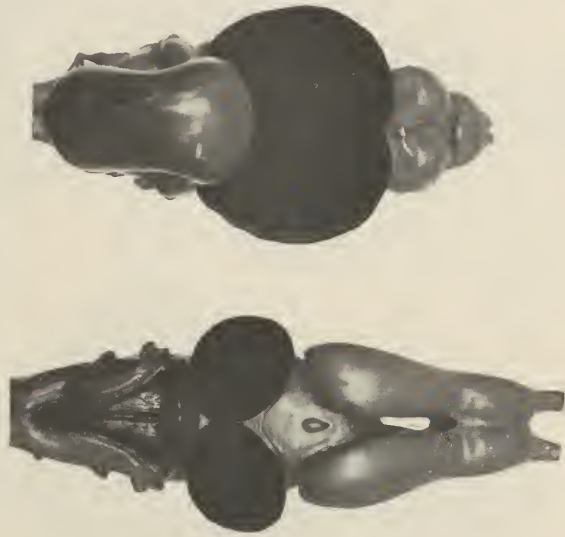


FIG. 347.—Diagrammatic representation of the mesencephalon (midbrain) in the vertebrate series. Dorsal view. Darkened area.

Salmo salar (salmon) above. *Rana esculenta* (frog) below.

segmental portion, the *tectum mesencephali*. Like other suprasegmental parts of the nervous system, the tectum is capable of great expansion to meet the demands of adaptation, and its constituents are disposed in positions best suited to this purpose. The gray matter occupies the outer surface, while the main mass of white matter is situated in the interior. This arrangement results in the formation of a cortex in many respects similar to that of the cerebellum. Indeed, the cortical formation is even more elaborate in the midbrain, although its surface expansion is less than that of the cerebellum.

The Tectum in Birds. The degree of expansion in the cortex of the tectum mesencephali has become so marked in certain animals that this part of the brain is recognized as a special lobe, the *lobus opticus*. This is especially true in birds which, in response to the dominant importance of the function of the eye, develop an exceptionally large lobus opticus.

According to several authorities, the cortex of the tectum mesencephali

in birds consists of many strata of nerve cells and fibers. Bellonci recognizes nine layers, Stieda twelve layers, and P. Ramon fourteen, which Cajal summarizes as follows:

The cortex of the lobus opticus in birds is arranged in three series of strata, an external formation of seven layers of nerve cells and fibers, an intermediate formation of five layers and an internal formation of two layers.

THE EXTERNAL FORMATION. The first stratum is a layer of optic fibers derived from the optic tract.



FIG. 348.—Diagrammatic representation of the mesencephalon (midbrain) in the vertebrate series. Dorsal view. Darkened area.

Alligator mississippiensis (alligator) above. Columba (pigeon) below.

The second stratum is a layer of small fusiform cells with moderately long axis cylinder processes. It also contains cells of a still smaller type with short axones, cells having axones parallel to the surface of the lobe, and small pyramidal cells having long axones.

The third stratum is a molecular or plexiform layer consisting of the arborizations from the first two strata. Occasional small or pyramidal cells are scattered among these fibers.

The fourth stratum is a layer of large ganglionic and small stellate cells with axis cylinders which penetrate to the seventh layer. It also contains small cells whose axis cylinders ramify in the fifth and seventh layers, small fusiform cells and stellate cells with expansive dendritic processes whose axones reach the medullary substance.

The fifth stratum is a plexiform layer which consists of the protoplasmic processes of the subjacent layer and the arborizations of the optic fibers. It contains some cells resembling the smaller elements of the outer molecular layer.

The sixth stratum consists of fusiform and ovoid cells with short dendritic trunks rapidly forming thick transversely disposed branches, the axis cylinders of which are long and enter the medullary substance. Other cells in this layer are ovoid bodies, smaller in size, and with short axones which descend to the eighth and ninth layers.

The seventh stratum is essentially a plexiform layer and contains the arborizations of the optic fibers together with a few small cellular elements.

THE INTERMEDIATE FORMATION. The intermediate formation consists of a large number and variety of cells. The majority of these cells send their dendrites peripherally into the external formation and their axones into the medullary substance.

The eighth stratum consists of globular cells with rich dendritic processes and axones which descend into the medullary substance. It also contains fusiform cells with short descending axones which reach the ninth layer. In addition to these there are pyramidal or triangular cells with long axis cylinders. Their bodies are large. The axis cylinders enter the medullary substance without much collateralization in the subjacent layers. Horizontal fusiform ganglionic cells analogous to those in the other layers, and triangular ganglionic cells with long divergent dendrites and axis cylinders which enter the medullary substance, are also found in this stratum.

The ninth stratum is an intermediate plexiform layer containing the arborizations of cells in the eighth layer and collaterals of the long axones situated in the more superficial layers.

The tenth stratum consists of cells which are ovoid and have ascending axis cylinders. Some of the cells are pyramidal and have long axis cylinders which enter the medullary substance. There are also ganglionic cells with



FIG. 349.—Diagrammatic representation of the mesencephalon (midbrain) in the vertebrate series. Dorsal view.

Lepus (rabbit) above. *Canis familiaris* (dog) below.

rich dendritic processes and descending axones which enter the medullary substance.

The eleventh stratum is a plexiform layer consisting of the arborization of axones and dendrites. It contains a few nerve cells of different varieties.

The twelfth stratum is also a plexiform layer, but contains fewer nerve cells than the eleventh stratum.

THE INTERNAL FORMATION. The internal formation consists of two layers:



FIG. 350.—Frontal section of the optic lobe in lizards (*Lacerta muralis*). Golgi's method. The left part of the picture shows the 14 layers which can be distinguished in the carmine or Weigert-Pal preparations. The numbering of the layers is done here inversely to that adopted for the birds. (*P. Ramon.*)

A—Cell with axis cylinder. B, E—Ascending axis cylinder cells. H—Ganglionic cells.

The thirteenth stratum consists of a large number of medium sized cells, triangular and stellate in shape, with long divergent dendrites and long axones which enter the medullary substance.

The fourteenth stratum, also called the medullary zone, consists of the deep nerve fibers of the optic lobe. The fibers comprise efferent and afferent axones. The efferent fibers of the fourteenth layer are arranged in several groups:

1. A fasciculus which enters the commissure of Gudden and thence passes to the central nucleus of the optic thalamus, constituting the *fasciculus strio-thalamicus* of Edinger.

2. A fasciculus which descends to the medulla and spinal cord and constitutes the *fasciculus bulbo-spinalis* of Edinger. This bundle undoubtedly acts in a reflex capacity connected with the movements of the eye.

3. A fasciculus arising in the pyramidal cells of the eighth and ninth

layers, destined in part for the posterior commissure and in part for the *fasciculus tecto-spinalis* of Edingers.

The afferent fibers of the fourteenth layer are arranged in two groups; *i.e.*, those which terminate in end-pencils and those which end in brushes. Both types of axones bear impulses to the optic lobe from adjacent areas of the tectum mesencephali.

The Tectum in Reptiles, Amphibia and Fish. Its Reduction in Mammals.
The elaborate stratification of the cortex of the optic lobe seen in birds



FIG. 351.—Frontal section of the optic lobe of the frog showing the fourteen layers. Golgi's method. (P. Ramon.)

FIG. 352.—Antero-posterior section of the optic lobe of the sparrow. Golgi's method. (P. Ramon.)

A, B, C—Types of cells. D—Cells with long axis cylinders. a, b, c—Arborizations of optic fibers from the retina.

indicates to what extent correlation of impulses is made possible in the midbrain. A similar elaborate design is seen in the mesencephalic cortex of the lower vertebrates. The optic lobe of reptiles is strikingly similar to that of birds. The reptilian cortex as a whole, however, shows less demarcation between the layers than in the avian midbrain.

The optic lobe in fish has been more carefully studied than in reptiles and amphibians; and while its cortex shows the same elaborate stratification, fewer layers have been identified. The number varies from eight to ten.

In mammals a great reduction in the elaborate arrangement of the cortex of the tectum mesencephali has occurred. The cortex in this region is dis-

tinctly vestigial as compared with that of the lower forms. The explanation for this reduction depends upon the shift of visual function to another and newer part of the mammalian brain.

Evolution in the Form of the Tectum Mesencephali. The roof of the midbrain has undergone a number of changes during the process of evolution. In its simplest form, the tectum mesencephali appears as an expanded arch over the ventricle of the mesencephalon. Laterally, it rests upon the expanded alar plates which serve to support the roof. The tectum mesencephali is divided into two bilaterally symmetrical halves by a slight ridge in the midsagittal plane which determines the corpora bigemina. To the corpora bigemina come the fibers of the optic tract, so that the tectum receives and correlates the visual impulses. This area is the tectal region. In selachians, it is exclusively visual in function. The expanded portion of the alar plate



FIG. 353.—Frontal section of the optic tectum in fish (*Barbus fluviatilis*), showing the ten layers. Golgi's method. (P. Ramon.)

1. Epithelial layer. 2. Central gray substance. 3. Deep white substance. 4. Middle gray substance. 5. Large plexiform layer. 6. Large fusiform cells and deep optic fibers. 7. Deep plexiform layer of the retinal formation. 8. Middle layer of optic fibers. 9. Superficial plexiform layer of the retinal formation. 10. Superficial layer of optic fibers. A—Ependymal cells. B, C—Large cells with branching dendrites. D—Cell with centrifugal axis cylinder going to the retina. E—Large cells of the 5th layer.

is the *collicular region* which serves as the end station of the somesthetic pathway. The association axones from this collicular region enter the tectum, and in this manner provide the means of correlation between somesthetic and visual impressions.

The character of the tectum mesencephali in the bony fish and ganoids is the same as in the selachians, where it presents a tectal and a collicular region. In amphibians, however, the tectal region shows a still further subdivision consequent upon the appearance of the newly differentiated system of receptors for the cochlear system, and the development of structures forming the middle ear. It is not only subdivided in the median line by the *interbigeminal sulcus*, but near its caudal extremity a transverse sulcus crosses the former at right angles. These sulci differentiate the two large superior corpora quadrigemina (superior colliculi), and the two small

inferior corpora quadrigemina (inferior colliculi). This change in the surface of the tectal region results from two distinct functional necessities; first, the correlation of visual impulses, and second, the correlation of auditory impulses. The tectum mesencephali not only makes provision for the elaboration of individual sensory impulses received from the eye, ear, muscles, joints or skin, but also serves to correlate these several types of sensory impressions.

The same general arrangement of the tectal region exists in reptiles. In birds the only notable change in this region is the greater expansion of the superior corpora quadrigemina which now form the avian *optic lobes*. The small inferior corpora quadrigemina situated caudal and mesial to the optic lobes are relatively insignificant, due to the fact that the auditory sense has not yet assumed its ultimate wide sphere of influence. The collicular region is not so prominent in birds as in the lower forms; it shows some tendency for the somesthetic pathway to shift its endings forward into the thalamus, a process which is eventually accomplished in the development of the mammals.

It is in the mammals, however, that the great change in the tectum mesencephali makes its appearance. This change is expressed in a marked reduction both in prominence and relative size of the tectum. In the mammalian midbrain the roof of the mesencephalon appears as the *quadrigeminal plate* which, in effect, is the homologue of the tectum mesencephali in the lower forms. This quadrigeminal plate is divided into four subequal bodies, two situated cephalad, the corpora quadrigemina superior, and two situated caudad, the corpora quadrigemina inferior. The superior corpora quadrigemina receive but few fibers from the optic tract. The inferior corpora quadrigemina receive the fibers from the lateral fillet which forms the connecting link in the pathway from the cochlea to the brain.

In the lower forms, this portion of the tectum mesencephali is the final ending of the auditory pathway. It constitutes the cortex wherein the sensory correlations of audition are accomplished. In mammals, on the other hand, such is no longer the case. The inferior corpora quadrigemina here serve as way stations *en route* to expansive cortical areas of auditory consciousness.

In summary, the mammalian brain presents a reduction in the size and importance of the tectum of the midbrain, because this region no longer officiates in its former important capacity in relation to visual and auditory functions.

The collicular portion of the midbrain in mammals has ceased to serve as the end station for the somesthetic pathway, which has shifted its relay stations forward into the optic thalamus and its end stations into the cerebral cortex.

Morphological Limitations to Expansion of the Midbrain. In spite of the elaborate cortex of the optic lobe, the tectum mesencephali has been hampered in its tendency to fullest expansion by the growth of the forebrain and of the hindbrain. At some critical period the optic lobe apparently

failed to provide for the visual differentiations which became necessary in color, in form, in size and motion, in direction and distance. It was inadequate for the more complex plurisensory combinations, and was insufficient to meet the new visual demands which came into existence with the appearance of the mammals. Some as yet undeveloped suprasegmental area was needed to make provision for the further expansion of visual elaboration and association. Such a suprasegmental structure made its appearance in the development of the endbrain, in which the psycho-associational reflex was consummated in its final and fullest extent. With the inauguration of the age of mammals there came a general shift forward of all higher centers for sensibility. It seems probable that in this shift the visual function has been a dominant factor if not an actual leader in the transference of sensory allegiance to the endbrain. Some of the elements of this progression are not altogether new, but were laid down in primitive outline even in the earliest vertebrates. The lateral geniculate body is the chief relay station of the visual fibers on their way to the cerebral cortex in mammals. The fundament of this body is found in the selachians as the *corpus geniculatum laterale*, a derivative of the thalamus which receives a few optic fibers. Throughout the entire vertebrate series the tendency for this shifting forward of the visual function is in evidence. In fish the optic fibers preempt the tectum mesencephali; in amphibia, reptiles and birds there is a shift cephalad in the caudal portion of the tectum to provide for auditory function. In the mammal from 80 to 90 per cent of the visual fibers have shifted to the geniculate body and the thalamus, whence they make their way to the visual cortex. In man it is doubtful whether any visual fibers actually terminate in the tectum mesencephali.

Telencephalization. The shifting forward of the sensory and motor functions of the brain is called *telencephalization*. As a process it has undoubtedly been stimulated by the transference of the visual center from the tectum opticum to the cerebral cortex. The midbrain in consequence has not only lost its primitive importance as the end station for vision, but it has also given up its fundamental relations to auditory and somesthetic sensibility. The superior corpora quadrigemina, in mammals and man, the remnant of the former extensive optic lobe, retain but small measure of their former dominance. The *visual fibers* pass them and employ other relay stations to reach their destinations in the cerebral cortex. A small number of fibers, probably *light fibers*, end in the superior corpora quadrigemina. These fibers, by means of synaptic connections, establish communication with the oculomotor nuclei, and thus regulate the size of the pupil in order to control the illumination of the retina. In this sense, the visual portion of the tectum mesencephali has transferred its strictly visual functions to the occipital cortex and has become a subsidiary reflex center for the protection of the retina. The inferior corpora quadrigemina likewise have lost much of their primordial significance as end stations for hearing. They now serve as way stations for the auditory pathway from the cochlear to the auditory area in the cerebral cortex. In a similar manner the pathway for the some-

thetic sensibility has found a new relay station in the nuclei of the optic thalamus, whence the final link in this connection proceeds to the somesthetic areas in the cerebral cortex.

The process of telencephalization, characterized as it is by a forward shifting of all of the end stations for the different types of sensibility in the body, has been in the interest of more ample and effectual sensory associations, which have resulted in a great development of consciousness. This shifting forward has called into existence the part of the brain potentially capable of the greatest expansion, the cerebral cortex. With the growth of the cerebral cortex the mesencephalon has gradually lost its original prominence among the major divisions of the brain and has been overshadowed by the development of more recently acquired parts.

The Significance of the Tegmentum and Basis Mesencephali. The tegmentum, as in the medulla and pons, bears a direct relation to the receptors and effectors by means of the peripheral nerve fibers. The tegmentum mesencephali receives afferent fibers from the fifth nerve through the mesencephalic root of the trigeminus. Its efferent nerve fibers are related to the trochlearis or fourth cranial nerve, which supplies one of the muscles moving the eyeball, and to the oculomotor or third cranial nerve, which supplies all of the intrinsic as well as the extrinsic muscles of the eyeball, with the exception of the *external rectus* and *superior oblique*.

The basis mesencephali is similar in its significance to the pons. It represents the collected mass of fibers which serve to connect the cerebral pallium with the cerebellum, in addition to which it contains the great pallio-spinal pathway, the pyramidal system. In this light, it may be said that the cerebral peduncles stand as an index to the extent of cortical development in the same degree that the pons is representative of this development.

EMBRYOLOGY OF THE MESENCEPHALON

Differentiation of the Corpora Quadrigemina. In the early stages the midbrain is one of the most prominent divisions of the encephalon and retains its prominence until relatively late in the course of growth, when the endbrain becomes the dominant element which overshadows all other structures. The fusion of the neural plates in the head region takes place earliest in the area of the future midbrain. The lateral walls of the mesencephalic tube appear as the basal and alar plates. The cavity enclosed by this portion of the brain is the mesencephalic ventricle. After fusion of the neural folds along the mid-dorsal line in the metencephalon and prosencephalon, the midbrain is demarcated from the hindbrain and the forebrain by means of two sulci which surround the tube, the *anterior* and *posterior isthmian sulci*. Shortly after the midbrain is demarcated in this manner, its roof plate begins to expand rapidly to form the tectum mesencephali. This expansion in the roof is due to an active migration of cells from the mantle layer in the alar plate. As the roof plate begins to thicken, due to invasion from the alar plates, there appears in the midsagittal line a longitu-

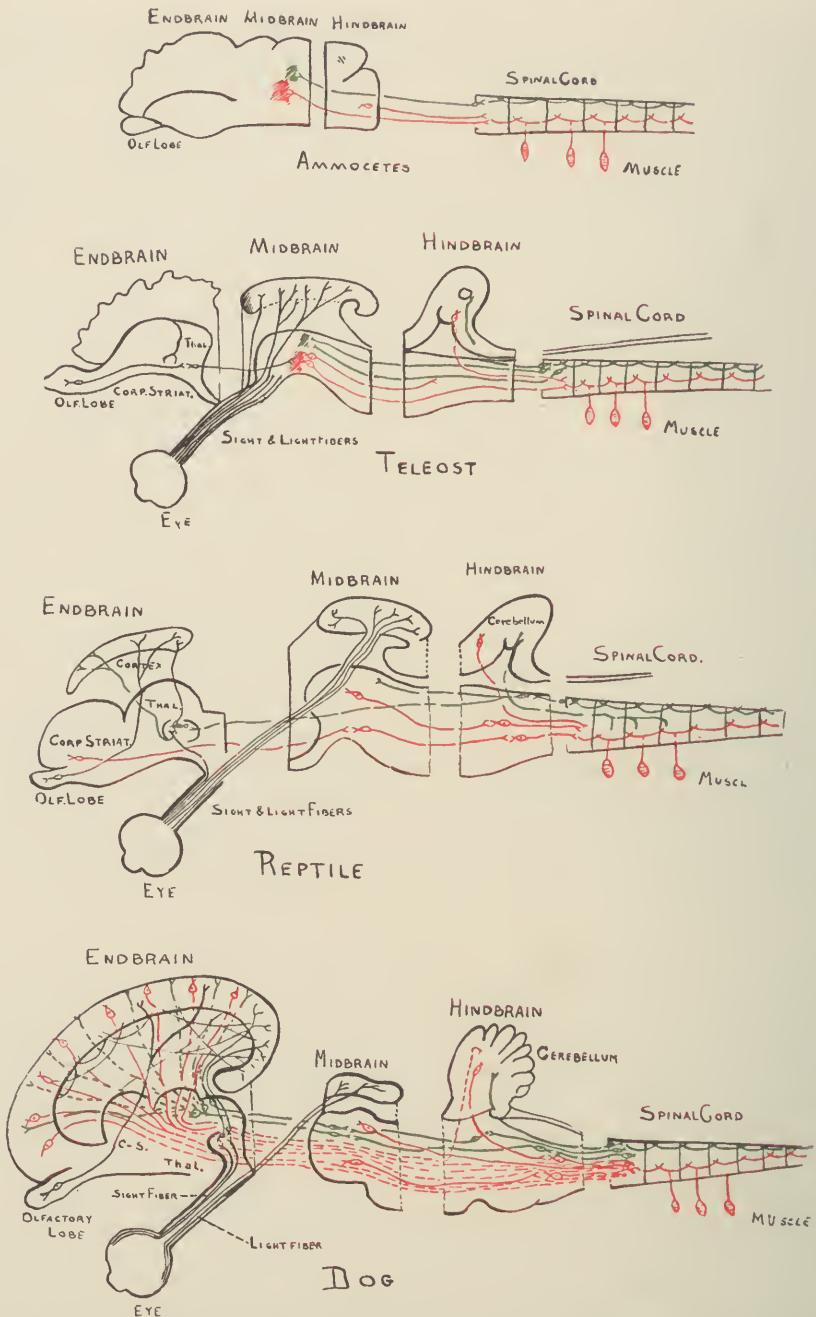


FIG. 354.—The diagram represents schematically the evolutionary process of telencephalization, showing the gradual stepping-up process in the successive cephalad shifts from one level to another. The black lines represent the special sense fibers, smell and sight, the red lines indicate the motor systems, the green lines the sensory systems. The solid lines represent the phylogenetically ancient systems, the broken lines the phylogenetically recent systems. (Modified from von Monakow.)

dinal ridge which subsequently becomes a sulcus and divides the roof plate into two symmetrical halves known as the *corpora bigemina*. Subsequently a transverse sulcus intersects the longitudinal ridge and the roof plate is thus divided into two sets of symmetrical bodies. The roof is then known as the *quadrigeminal plate* and the two sets of bodies in it are respectively the *superior corpora quadrigemina* and the *inferior corpora quadrigemina*. Toward the end of fetal life the pineal gland is tilted backward in most mammals by the development of the corpus callosum and comes to rest upon the quadrigeminal plate immediately between the superior corpora quadrigemina. Its presence produces a small groove, the *subpineal fossa*.

Histogenesis of the Midbrain. The portion of the neural tube giving rise to the midbrain resembles in its early histological character other portions of the neuraxis. It presents a typical ependymal, mantle and marginal layer.

The mantle layer differentiates in a manner similar to that of the cerebellum. At an early period there is an active migration of neuroblasts into the tectum where the cells proliferate and develop the stratified cellular layers forming the superior and inferior colliculi. The more superficial layers resemble those in the cortex of the cerebellum, while the deeper layers correspond to the medullary and tegmental nuclei. Fibers from the optic tract and lateral fillet may be traced to the colliculi by the end of the third month. The optic fibers establish connections with the superficial ganglionic layer of the superior colliculus, while the lateral fillet extends over the surface of the inferior colliculus. During this period the inferior brachium makes its appearance, connecting the inferior colliculus with the mesial geniculate body.

The nuclei of the third and fourth cranial nerves differentiate as discrete collections of neurocytes, which maintain a position near the floor of the mesencephalic ventricle. This relation is similar to that obtaining in the other cranial nerve nuclei.

The emergent root fibers of the fourth nerve follow an aberrant course in leaving the midbrain. They extend caudally and dorsally to decussate in the superior medullary velum.

The central gray matter of the midbrain resembles that found in other parts of the neural tube. In the early stages the cavity of the midbrain forms a spacious ventricle. This cavity, however, becomes much reduced in size until it forms the narrow canal constituting the *aqueduct of Sylvius*. During the process of reduction in the mesencephalic ventricle there is a tendency to develop several accessory recesses, two of which come into relation with the superior colliculi and two with the inferior colliculi. These recesses, however, are transitory and soon disappear.

Concerning the origin of the largest collections of neurocytes in the midbrain, the *nucleus ruber* and *substantia nigra*, little is definitely known at the present time. The nucleus ruber develops from the mantle layer apparently as a portion of the formatio reticularis, and is sharply defined by the end of the third month. At this time its connection with the decussating

superior cerebellar peduncles may be clearly recognized. It is probable that the substantia nigra has a similar origin.

ANATOMY OF THE MESENCEPHALON

Situation, Boundaries and Relations. The mesencephalon occupies the aperture of the tentorium cerebelli and rests upon the dorsal portion of the dorsum sellæ. Its cephalic limit is determined by a plane passed through the base of the pineal gland and the posterior borders of the mamillary bodies. Its caudal limit is determined by a plane passed through the most cephalic limit of the pons and the cephalic extremity of the superior medullary velum.

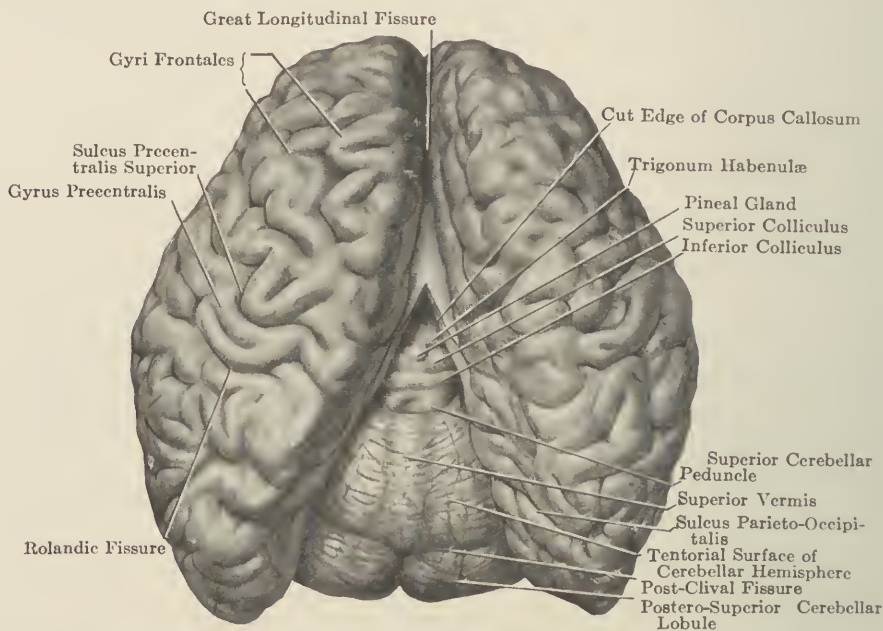


FIG. 355.—Exposure of the dorsal surface of the midbrain and the tentorial surface of the superior cerebellar vermis.

Dimensions and Coverings. The mesencephalon is 13 mm. in its long axis on its dorsal surface, and 9 mm. on its ventral surface in the same axis. In sagittal section its cephalo-caudal length is 11 mm. It is 23 mm. in its greatest transverse diameter. The midbrain is covered on all sides by the pia mater, which closely invests it and conveys its vascular supply. Along its ventral surface, and particularly in relation to the cerebral peduncles, the arachnoid bounds a subarachnoid space which contains a relatively large amount of cerebrospinal fluid. This is the *cisterna basalis* which is continuous caudad with the cisterna pontis and the cisterna magna.

Surfaces of the Mesencephalon. The midbrain presents a dorsal and a ventral free surface and two lateral surfaces which are in part exposed and in part concealed by adjacent portions of the brain.

THE DORSAL SURFACE. The dorsal surface in the midline presents a longitudinal groove, the *sulcus longitudinalis*, which is crossed at right angles by a transverse groove, the *sulcus transversus*. These sulci divide the quadrigeminal plates into four symmetrical elevations or colliculi, two on either side, the superior corpora quadrigemina or nates and the inferior corpora quadrigemina or testes. The superior colliculi are slightly larger than the inferior colliculi. The cephalic extremity of the *sulcus longitudinalis* becomes expanded to form a triangular groove in which the pineal gland rests; this is the *trigonum subpineale* or *subpineal fossa*.

The superior colliculi are 7 mm. in length, 10 mm. in width, and 6 mm. in height. They are connected by the *superior brachium* extending cephalo-

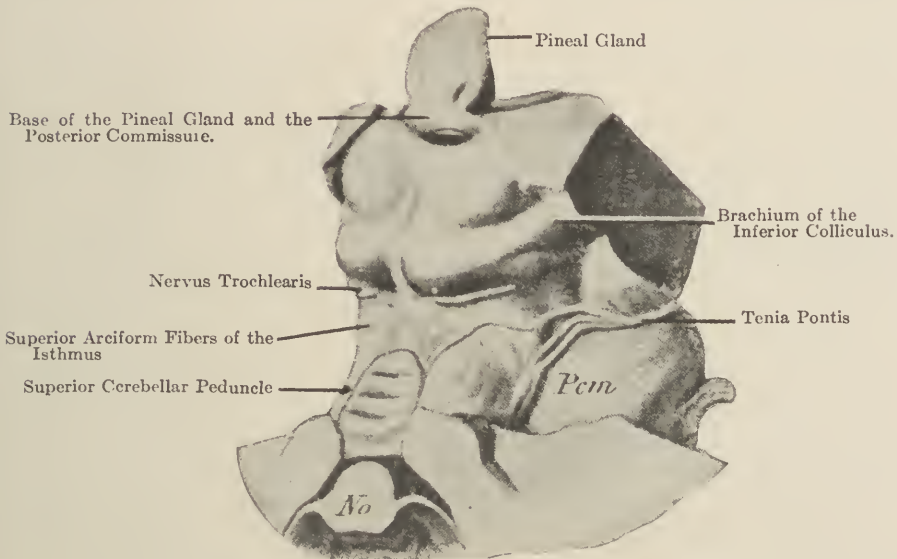


FIG. 356.—The dorsal surface of the mesencephalon. (Quain.)

Pcm—Middle cerebellar peduncle. No—Nodulus of cerebellum.

laterally to the lateral geniculate body (*corpus geniculatum laterale*). This structure forms the connection by which the optic fibers make their way to the superior colliculus and thus determines the reflex light pathway.

The inferior colliculi are 6 mm. in length, 8 mm. in width, and 5 mm. in height. They are connected by means of the *inferior brachium* with the mesial geniculate body (*corpus geniculatum mediale*).

THE VENTRAL SURFACE. The ventral surface of the mesencephalon consists of the two cerebral peduncles. Beginning at the cephalic margin of the pons, these peduncles diverge toward the cerebral hemisphere at an angle of 30 to 45 degrees. At their cephalic extremities they are crossed by the optic tracts, and the area bounded by these tracts and the cerebral peduncles forms the *optico-peduncular space*. The portion of this space comprised between the peduncles at the cephalic extremity of the pons is the *interpeduncular space*. This area varies in its transverse diameter from 3

to 4 mm. in its relation with the pons, to 18 or 20 mm. in its relation with the mammillary bodies.

The interpeduncular space is bounded posteriorly by the cephalic fibers of the pons, beneath which it may be traced into a blind pocket, the *foramen cecum anterius*. The anterior boundary of the interpeduncular space is the posterior surface of the mammillary bodies, at the base of which is the post-mammillary recess. The *ponto-peduncular sulcus* indicates the transition from pons to cerebral peduncle. Extending along the inner margin of either peduncle and parallel to the peduncular surface is the *sulcus oculomotorius*, from which the third cranial nerve fibers make their emergence from the brain-stem.

THE LATERAL SURFACES. Either lateral surface of the midbrain is uncovered by other structures in its caudal two-thirds. This uncovered portion consists of the posterior corpora quadrigemina and the inferior brachium. Below the brachium is a slight triangular depression having its apex directed toward the cerebral hemisphere and its base toward the pons. This is the *trigonum lemnisci*, which indicates upon the surface the position of the *lateral fillet* in its course toward the inferior corpus quadrigeminum. The upper margin of the trigonum lemnisci is bounded by the superior cerebellar peduncle, its lower margin is formed by the lateral surface of the cerebral peduncle. The portion of the neuraxis represented by the trigonum lemnisci is sometimes called the *isthmus*.

The exposed lateral aspect of the midbrain presents the following structures enumerated in the dorso-ventral direction: (1) The lateral aspect of the posterior corpus quadrigeminum; (2) the brachium posterius; (3) the superior cerebellar peduncle; (4) the trigonum lemnisci; (5) the lateral aspect of the cerebral peduncles.

The dorsal surface of the mesencephalon is concealed by the splenium of the corpus callosum and the overhanging portions of the cerebral hemispheres.

The Blood Vessels of the Mesencephalon. The midbrain receives its arterial supply from the following vessels:

THE MEDIAN PEDUNCULAR ARTERIES. These arteries are a continuation of the median arteries of the pons. They spring in part from the cephalic extremity of the basilar artery and in part from the junction of the basilar and posterior cerebral arteries. A few branches take origin from the posterior communicating artery. After ascending for a considerable distance they penetrate into the interpeduncular space. Some branches, however, known as the *radicular arteries*, enter the oculomotor sulcus and pass inward accompanying the emergent fibers of the third nerve. When they reach the tegmental portion of the midbrain the arteries are distributed to the various structures of this region, including the fillet, the superior cerebellar peduncle, the red nucleus and the nuclei of the third and fourth nerves. The vessels are of the terminal type. They do not form anastomoses with each other in their course or at their termination. The nucleus of the third nerve, in

particular, has a completely independent circulation which does not communicate either with the vessels of the colliculi or with the opposite nucleus.

THE LATERAL PEDUNCULAR ARTERIES. The lateral peduncular arteries are more variable in their volume and course. They arise either from the posterior cerebral artery or the posterior communicating artery. Some branches, however, are derived from the anterior chorioid and superior cerebellar arteries. They penetrate the ventral and lateral surfaces of the peduncle and are distributed to the basal portion of the midbrain.

THE VEINS OF THE MIDBRAIN. The veins of the midbrain are small in size and extremely irregular in their course. They empty chiefly into the basilar veins.

CHAPTER XXIX

THE MIDBRAIN

INTERNAL STRUCTURE AND HISTOLOGY OF THE MESENCEPHALON

The internal structure of the midbrain is best illustrated in five successive sections at the following levels:

1. Through the inferior colliculus.
2. Through the transverse intercollicular sulcus.
3. Through the caudal extremity of the red nucleus.
4. Through the superior colliculus and the mesial geniculate body.
5. Through the superior colliculus, pulvinar and lateral geniculate body.

In each section the characters of the following parts are to be noted: The gray and white matter of the tectum mesencephali, the gray and white matter of the tegmentum mesencephali, and the white matter of the basis mesencephali.

Section Through the Inferior Colliculus. ARRANGEMENT OF THE GRAY MATTER IN THE TECTUM MESENCEPHALI. The gray matter in the inferior colliculus presents three divisions: (1) The central nucleus; (2) the external cortex, and (3) the internuclear cortex.

The central nucleus consists of large and medium sized multipolar cells which are stellate and fusiform in shape. Their axones are long and enter the inferior brachium. In addition to the large cells there are small stellate cells with short axones and fusiform cells of medium size and triangular outline. Within the nucleus is a terminal plexus made up chiefly of end arborizations of the lateral fillet.

The external cortex of the inferior colliculus consists of two rows of cells, the outermost containing small cells measuring from 8 to 10 micra in diameter, and triangular, stellate or fusiform in outline. Their dendrites diverge in every direction. Their axones give off numerous collaterals whose destination is unknown. The second layer consists of triangular and pyramidal cells of medium size. These cellular elements vary from 8 to 14 micra in diameter. They possess several voluminous dendrites directed outward, while the axone is directed toward and probably enters the inferior brachium.

The internuclear cortex of the inferior colliculus consists of five layers:

1. The superficial fibrous layer.
2. The layer of small fusiform and stellate cells.
3. The layer of large multipolar cells.
4. The layer of the medullary substance.
5. The layer of the central gray matter.

Fibers of the superficial fibrous layer are continued into the inferior brachium. The axones of the cells in the second layer are short: their des-

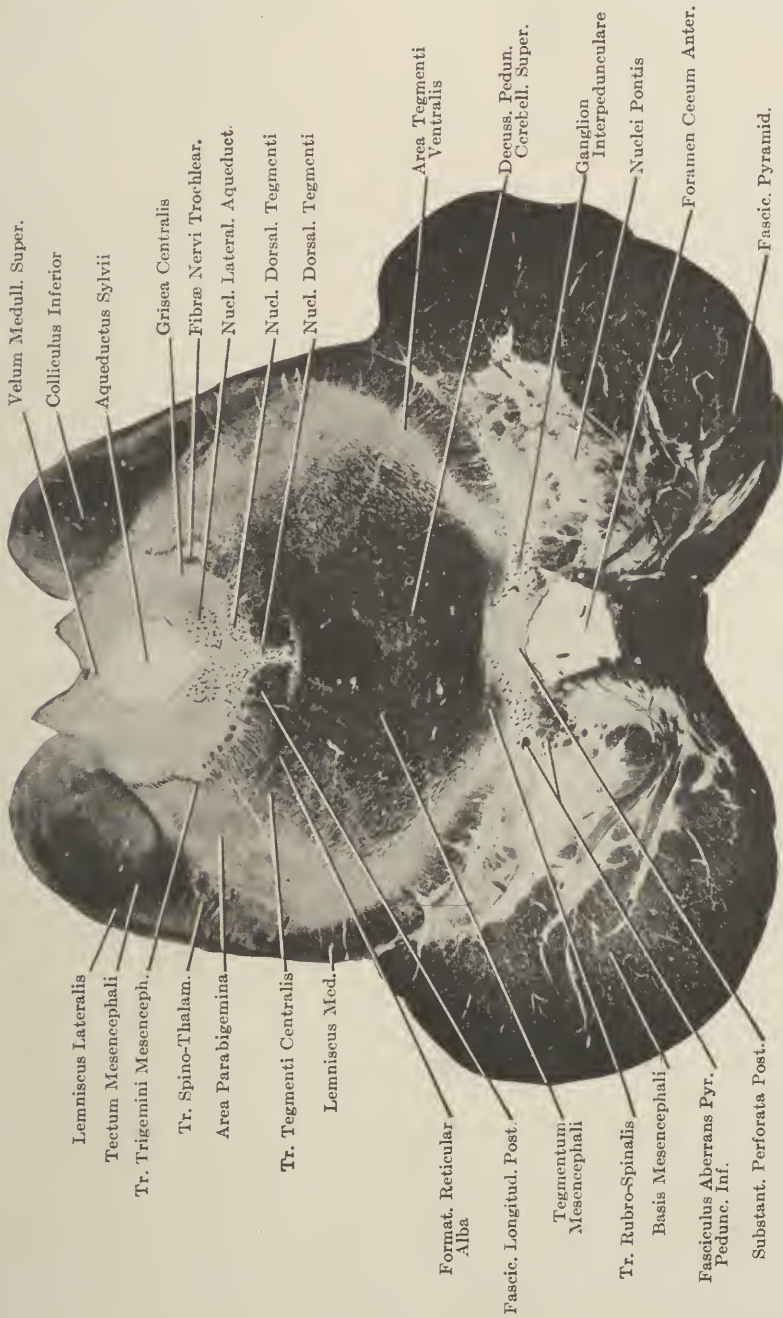


FIG. 357.—Cross section at level of transition from pons to midbrain (isthmus). (Serial section No. 716.)

tinuation is unknown. Some of these axones may make their way into the inferior brachium. The cells in the third layer are large multipolar elements

varying in size from 24 to 28 micra. Their axones are thick and descend to participate in the formation of the reflex acoustic pathway. The fibers constituting the white matter of the inferior colliculus are of two types:

The first type comprises the reflex fibers terminating in the inferior colliculus, and the central fibers which pass through the inferior colliculus to end—at least in large measure—in the mesial geniculate body.

Fibers of the second type, constituting the central acoustic reflex fasciculus, pass for the most part from the inferior colliculus.

ARRANGEMENT OF THE GRAY MATTER IN THE TEGMENTUM MESENCEPHALI. The central gray matter is oval in shape. Its dorsal aspect is in contact with the *commissura corporis quadrigeminae posterioris*; its ventral aspect is in relation with the posterior longitudinal fasciculus. Near its center is the aqueduct of Sylvius. Its lateral aspects come into relation with the mesencephalic root of the fifth nerve. Situated in the midline is the *nucleus dorsalis raphé* (dorsal nucleus of the raphé), immediately lateral to which upon either side is the *nucleus trochlearis*. Dorsal to the trochlear nucleus is a collection of cells constituting the *nucleus dorsalis tegmenti accessorius*.

Ventro-lateral to the central gray matter is the *substantia reticularis tegmenti* which contains no specialized nuclear groups at this level. On the border between the tegmentum and basis mesencephali is the *substantia nigra*, a large nucleus extending from the midline toward the lateral surface of the midbrain.

WHITE MATTER OF THE TEGMENTUM. A conspicuous collection of nerve fibers constitutes the decussation of the superior cerebellar peduncles. This crossing takes place immediately in front of the central gray matter. Lateral to the superior cerebellar decussation is the mesial fillet which now occupies a position extending ventro-dorsad and reaching from the midline toward the lateral periphery. At its lateral extremity are some of the fibers of the lateral fillet which have not as yet established their connections with the inferior corpora quadrigemina. The *fasciculus longitudinalis posterior* lies in close relation to the nucleus trochlearis while lateral to both is the *fasciculus predorsalis*. Ventral to the fasciculus predorsalis is the *central tegmental tract*, and ventro-lateral to the decussation of the superior cerebellar peduncle is the *rubrospinal tract*. Ventral to the inferior corpus quadrigeminum is the spino-thalamic tract, while along the periphery is the brachium inferius.

WHITE MATTER OF THE BASIS MESENCEPHALI. The basis mesencephali is composed exclusively of fibers which pass from the cerebral cortex to the bulb, pons, and spinal cord. These fibers are grouped in three fasciculi, the most mesial of which is the *frontal pallio-pontile tract*, while the most lateral is the *occipito-parieto-temporal pallio-pontile tract*. Interposed between these fasciculi of the basis are the *cortico-spinal* and *cortico-nuclear tracts*, representing the pyramidal system. Dorso-mesial to the occipito-parieto-temporo-ponto-cerebellar tract is a group of *aberrant pyramidal fibers* making their way to the mesial fillet. This bundle constitutes the

pes lemniscus profundus. Dorsal to the fronto-ponto-cerebellar tract is another group of aberrant pyramidal fibers which are also making their way to the mesial fillet. This bundle constitutes the *pes lemniscus superficialis*. Both of these groups of fibers are especially concerned in oculogyric and cephalogyric movements.

Section Through the Intercollicular Sulcus. ARRANGEMENT OF THE GRAY AND WHITE MATTER IN THE TECTUM MESENCEPHALI. The constituents of this portion of the midbrain have been greatly reduced in number and prominence. There appears no recognizable stratification as in the colliculi. The outer layer consists of the *stratum zonale*, internal to which is a layer of indefinite dimensions, the *stratum opticum*, consisting for the most part of nerve fibers with a few scattered nerve cells. The diminution in cellular and fiber elements in this region is due to the fact that the intercollicular sulcus is an area intermediate between the superior and inferior colliculi.

THE GRAY AND WHITE MATTER OF THE TEGMENTUM MESENCEPHALI. The central gray matter is still oval in appearance and surrounds the aqueduct of Sylvius. Ventrally it contains the *nucleus dorsalis raphé*. Lateral to this nucleus is the nucleus trochlearis. Dorsal to the trochlear nucleus is the large *nucleus dorsalis tegmenti accessorius*. The lateral aspects of the central gray matter are in relation with the mesencephalic roots of the fifth nerve.

The gray matter in the rest of the tegmentum consists of a diffuse reticular formation bounded dorsally by the stratum profundum of the tectum, laterally by the lateral fillet and spino-thalamic tract, ventrally by the decussated superior cerebellar peduncle, and mesially by the central gray matter. It contains no well defined nuclear collections of cells, although the caudal extremity of the red nucleus is just beginning to appear on one side. Ventral to the mesial fillet and the decussating cerebellar peduncle is the extensive *substantia nigra* which consists of a collection of nerve cells and fibers occupying approximately one quarter of the entire tegmentum of the midbrain.

WHITE MATTER OF THE TEGMENTUM MESENCEPHALI. Near the midline and ventral to the central gray matter are the scattered bundles of the fasciculus longitudinalis posterior. Lateral to this bundle is the fasciculus predorsalis and central tegmental tract. Immediately ventral to the fasciculus longitudinalis posterior is the *ventral tegmental decussation of Forel*, adjacent to which are the two superior cerebellar peduncles. Lateral to the superior cerebellar peduncle is the mesial fillet. At the caudal extremity of this collection of fibers is the spino-thalamic tract, and lateral to it the brachium inferius.

WHITE MATTER IN THE BASIS MESENCEPHALI. The basis mesencephali at this level contains no gray matter and lies immediately ventro-lateral to the substantia nigra. It consists, as in the lower level, of four major fasciculi: (1) The frontal pallio-pontile tract; (2) the occipito-parietotemporal pallio-pontile tract; (3) the cortico-spinal tract, and (4) the

cortico-nuclear tract. The aberrant fibers of the pyramidal system pass through the substantia nigra toward the mesial fillet in which they finally



FIG. 358.—Cross section through the inferior colliculus. (Serial section No. 760.)

become incorporated. These fibers represent the *pes lemniscus profundus*. The rubro-spinal tract lies immediately ventral to the decussated bundles of the superior cerebellar peduncle. A few scattered bundles of fibers passing



FIG. 359.—Cross section through the midbrain at the level of the transverse intercollicular sulcus. (Serial section No. 776.)

dorso-mesial to the frontal pallio-pontile tract toward the tegmentum constitute the *pes lemniscus superficialis* of the aberrant pyramidal contingent. The caudalmost fibers of the oculomotor nerve sweep inward and downward toward the interpeduncular space.

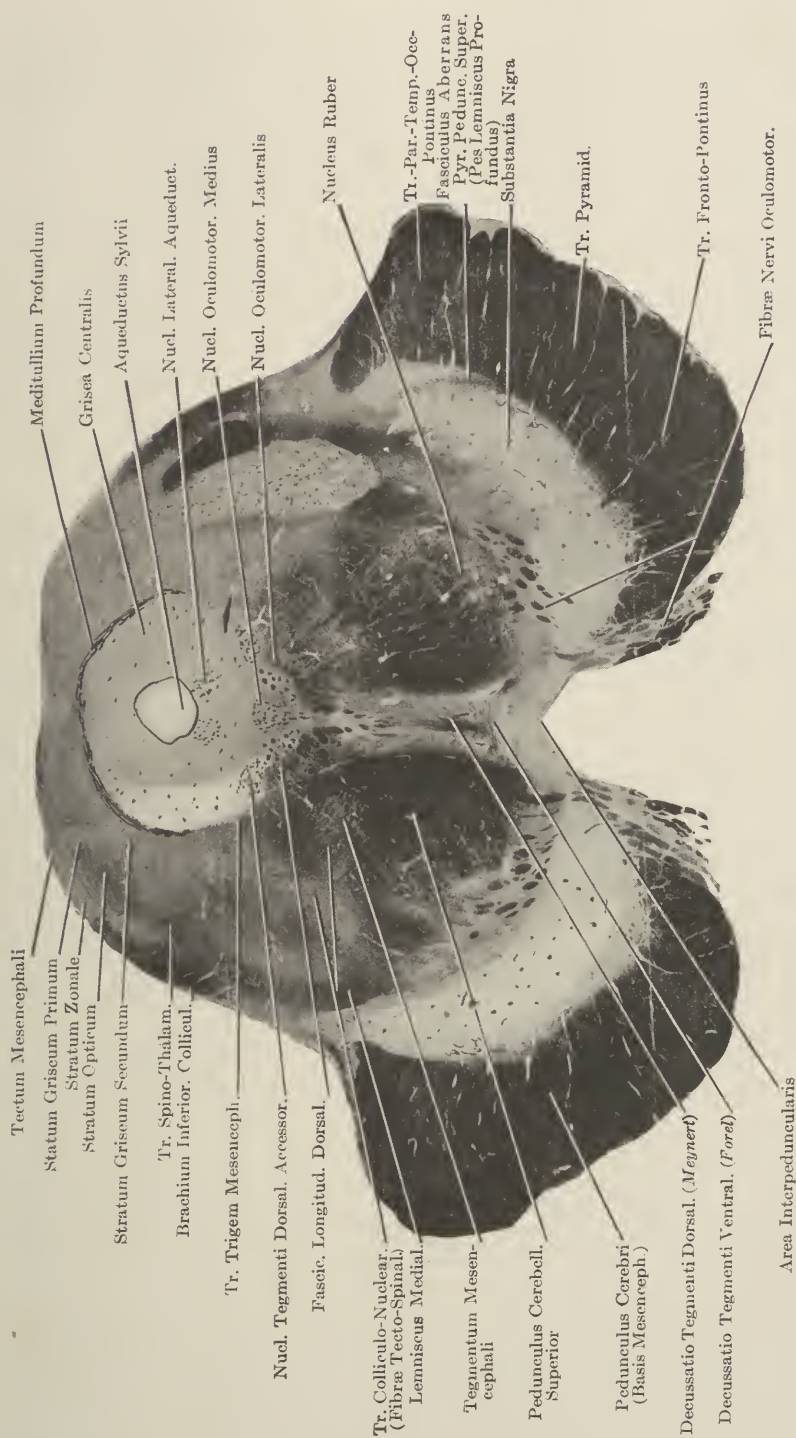
Section Through the Caudal Extremity of the Red Nucleus. GRAY MATTER OF THE TECTUM MESENCEPHALI. At this level the tectum mesencephali has four distinct zones: (1) the *stratum zonale*; (2) the *stratum griseum primum*; (3) the *stratum griseum secundum*; (4) the *stratum griseum tertium*. Mesial to the *stratum griseum tertium* is a thin band of white matter, the *meditullium profundum*. The two colliculi are connected across the midline by the commissure of the superior colliculi.

The cortex of the superior corpora quadrigemina is the homologue of the cortex of the optic lobe in birds.

WHITE MATTER OF THE TECTUM MESENCEPHALI. *Fibers of the Light Reflex.* The white matter of the superior colliculus consists of afferent fibers which make their way to the midbrain by the optic tract. In man they represent but a small portion of the optic fibers, being limited in all probability to those which conduct *light impulses*. The fibers which convey the visual or *sight impulses* are relayed in the pulvinar and lateral geniculate body.

The Colliculo-Nuclear Tract. The light fibers which end in the superior colliculus establish connection with a reflex or descending optic tract. This tract takes origin in the cells of the cortex of the tectum, especially in the large cells of the fourth layer. It completes a direct and a crossed connection with the brain stem. The portion of the tract establishing the crossed connection passes in front of the fasciculus longitudinalis posterior and the nucleus oculomotorius; here it reaches the midline, and, with its fellow of the opposite side, forms a complete crossing, the *fountain decussation* of Meynert. It sends ascending collaterals and terminal end branches into the nucleus oculomotorius, the nucleus trochlearis and the nucleus abducens of the side opposite its origin. The direct portion of this tract does not enter into the decussation of Meynert. It is less voluminous than the crossed tract, arises in a more cephalic portion, and descends as far as the upper part of the medulla oblongata. This tract terminates in the nuclei which control oculomotor movements.

GRAY MATTER OF THE TEGMENTUM MESENCEPHALI. The central gray matter at this level is circular in outline and encloses a nearly circular aqueduct of Sylvius. It presents a ventral prolongation containing the cells which form the *nucleus oculomotorius*. Dorsal to this nucleus is the *nucleus dorsalis tegmenti accessorius*. The dorsal aspect of the central gray matter is in relation with the commissure of the superior colliculus, while its lateral aspects are in contact with the *meditullium profundum* and the mesencephalic root of the fifth nerve. Surrounding the central gray matter is the reticular formation which at this level presents no specialized nucleus. The most ventral element in the tegmentum is the now much enlarged *substantia nigra*.



Area Interpeduncularis

FIG. 360.—Cross section through the midbrain at the level of the caudal extremity of the red nucleus. (Serial section No. 800.)

The Fasciculus Longitudinalis Dorsalis of Schütz, or the Peri-ependymal Longitudinal Tract. In the gray matter which surrounds the aqueduct of Sylvius there are many fine, myelinated fibers. These fibers are observed in sagittal and transverse sections. They may be traced as far cephalad as the *dorsal tegmental nucleus of Gudden* and the *fasciculus retroflexus of Meynert*. They constitute a longitudinal tract of considerable size beneath the ependyma of the central canal. Schütz recognized the portion of this fasciculus which extends between the trochlear and oculomotor nuclei. This he called the *fasciculus longitudinalis dorsalis*. It is known, however, that this is not the only portion of a system which in reality is more extensive and includes fibers extending into the superior and lateral regions about the aqueduct of Sylvius. A dorsal and a ventral system are recognizable in the fasciculus of Schütz. The dorsal portion lies in a position dorsal to the aqueduct of Sylvius, while the ventral portion lies ventral to the aqueduct in the gray matter. As a whole, the fasciculus of Schütz in its two portions surrounds the aqueduct, and for this reason is called the *peri-ependymal longitudinal tract*. This tract probably represents an ancient motor pathway whose significance will be discussed in detail in the description of the diencephalon.

WHITE MATTER IN THE TEGMENTUM MESENCEPHALI. The most conspicuous collection of fibers in the tegmentum is the superior cerebellar peduncle. Mesial and ventral to this fasciculus are the decussating fibers of the ventral tegmental decussation of Forel. Immediately dorsal to these fibers are other decussating axones which constitute the *dorsal tegmental decussation of Meynert*. Ventral to the nucleus oculomotorius is the now attenuated fasciculus longitudinalis posterior, lateral to which are a few bundles of the *fasciculus predorsalis*. Occupying a position lateral to the superior cerebellar peduncle is the mesial fillet which has now assumed the form of a crescent with its concavity turned toward the central gray matter. At its dorsal tip is the spino-thalamic tract. In a position lateral to the spino-thalamic tract is the massive bundle of the inferior brachium, while near the center of the reticular formation is a small fasciculus, the *central tegmental tract*. Many fine internal arciform fibers pass from the superior colliculus to the decussation of Meynert. These establish the reflex connection between the superior colliculus and the nuclei of the oculomotor mechanism.

WHITE MATTER IN THE BASIS MESENCEPHALI. The basis mesencephali is made up exclusively of white matter which is arranged in the three groups of fibers already described in the preceding section. The mesial group represents the frontal pallio-pontile tract, the lateral the occipito-parieto-temporal pallio-pontile tract, and the intermediate group, the cortico-spinal and cortico-nuclear tracts. Mesial to the occipito-parieto-temporal pallio-pontile tract are the fibers of the aberrant pyramidal contingent constituting the *pes lemnisci profundus*; while dorsal to the frontal pallio-pontile tract, in the interpeduncular space, is a small bundle of fibers constituting the *pes lemnisci superficialis*.

EMERGENT ROOT FIBERS CONNECTED WITH THE MIDBRAIN. At this level the emergent fibers from the oculomotor nucleus pass outward from the nucleus in an arciform manner. Some encircle the outer margin of the bundles of the superior cerebellar peduncle, while others pass directly through it into the sulcus oculomotorius.

Section Through the Superior Colliculus and the Mesial Geniculate Body. **ARRANGEMENT OF THE GRAY AND WHITE MATTER IN THE TECTUM MESENCEPHALI.** At this level the gray matter shows the same stratification as in the level immediately below. It has an outer *stratum zonale*, followed in regular succession by the *stratum griseum primum*, *stratum griseum secundum* and *stratum griseum tertium*. The superior colliculi are connected across the median line by the superior collicular commissure. The cortex of the superior colliculus has constituents similar to those already enumerated in the last section.

ARRANGEMENT OF THE GRAY MATTER IN THE TEGMENTUM MESENCEPHALI. *The Central Gray Matter.* The central gray matter at this level is triangular in outline and has its apex directed ventrad. It contains the medial and lateral nuclei of the *oculomotor nucleus*, dorsal to which is the *nucleus dorsalis tegmenti accessorius*, whose lateral and dorsal aspects have relation respectively with the mesencephalic root of the fifth nerve and the mediotullium profundum. The aqueduct of Sylvius is nearly circular in outline. Surrounding the aqueduct are the fibers of the *fasciculus longitudinalis dorsalis* of Schütz.

The gray matter in the tegmental portion of the midbrain presents no particular specializations of nerve-cells in its dorsal area. Ventrally, however, it begins to show the presence of two large round nuclei situated one on either side of the raphé, the *nucleus ruber*. In this nucleus many of the fibers of the superior cerebellar peduncle have their ending. Other peduncular fibers pass around the nucleus forming a capsule for it. Mesial to the red nucleus is a large group of cells constituting the *large celled nucleus of the median raphé*. The reticular formation throughout the rest of the tegmentum shows no specialization into nuclei. The *substantia nigra* at this level is somewhat reduced in size, and appears to have at its lateral termination a new extension of white matter, the *mesial geniculate body*, whose outer surface is invested by the fibers which, in the lower sections, constituted the inferior brachium. The mesial geniculate body consists of medium-sized, stellate and triangular cells, and serves as a relay station in the course of the auditory pathway. Although thus closely related to the midbrain, it is in reality a derivative of the next higher segment of the encephalon, the interbrain.

WHITE MATTER OF THE TEGMENTUM MESENCEPHALI. At this level the white matter in the tegmentum has undergone considerable change. The ending of many of the fibers in the superior cerebellar peduncle has reduced the size of this tract and its place is now taken in large part by the red nucleus. Some fibers of the superior colliculus are still entering the dorsal tegmental decussation of Meynert, which presents itself as a prominent



FIG. 361.—Cross section through the midbrain at the level of the superior colliculus and the median geniculate body. (Serial section No. 870.)

feature between the red nuclei. The mesial fillet, now much more compact and of smaller size, is situated lateral to the red nucleus, and at its dorsal extremity is the spino-thalamic tract. Ventral to the red nucleus and crossing the raphé is the beginning of the ventral tegmental decussation of Forel, out of which the rubro-spinal tract emerges.

WHITE MATTER OF THE BASIS MESENCEPHALI. The basis mesencephali consists, as in all of the lower sections, of the mesial group comprising the fronto-ponto-cerebellar tract, the lateral group comprising the occipito-parieto-temporo-ponto-cerebellar tract, and the intermediate group comprising the cortico-spinal and cortico-nuclear tracts. Dorso-mesial to the occipito-parieto-temporo-ponto-cerebellar tract are the fibers of the pes lemnisci profundus. A small group of fibers situated dorsal to the fronto-cerebellar tract at the margin of the interpeduncular space represents the pes lemnisci superficialis.

EMERGENT ROOT FIBERS CONNECTED WITH THE MESENCEPHALON. Emergent fibers of the third nerve pursue their typical course, some passing along the outer margin of the red nucleus and some passing through it. All of these fibers eventually bend inward and forward to emerge from the sulcus oculomotorius in the interpeduncular space.

Section Through the Superior Colliculus, Pulvinar and Lateral Geniculate Body. **ARRANGEMENT OF THE GRAY MATTER IN THE TECTUM MESENCEPHALI.** At this level the superior colliculus has become reduced in size and has lost much distinctness in its stratification. It still presents a well developed stratum zonale, but it is no longer possible to recognize the several other strata. The two colliculi are connected across the midline by a large strand of fibers which represents the caudal extremity of the posterior commissure. The longitudinal intercollicular sulcus has increased in depth and forms the caudal portion of the subpineal recess in which rests the pineal gland. Adjacent to the colliculus in a lateral position are the much enlarged mesial geniculate body and accessory geniculate body. Dorso-lateral to the mesial geniculate body is the pulvinar of the thalamus, from which the geniculate body is separated by a thin margin of nerve fibers constituted of axones derived from the inferior brachium and representing the continuation of the auditory pathway. Ventro-lateral to the mesial geniculate body is the *corpus geniculatum laterale* which, like the mesial geniculate body, is a large nucleus of gray matter. It is surrounded by a fairly thick margin of white matter derived from the optic tract. The lateral geniculate body serves as a relay station for the optic fibers on their way to the cortex. Some of these axones, however, pass by the geniculate body to the superior colliculus. In man these axones represent the *light fibers*, while the *sight fibers* after relay in the lateral geniculate body and pulvinar, pass on to the visual cortex in the occipital lobe. Some of the sight fibers which do not end in the lateral geniculate body make their way to the pulvinar of the thalamus and here, after receiving relay, join the fibers from the lateral geniculate body on their way to the visual area in the cerebral hemispheres.

GRAY MATTER OF THE TEGMENTUM MESENCEPHALI. The tegmentum of the midbrain at this level is much reduced in size.



Fig. 362.—Cross section through the midbrain at the level of the pulvinar and lateral geniculate body.

The Central Gray Matter. The central gray matter especially shows a reduction in size; it is triangular in shape and surrounds the circular aqueduct of Sylvius. Its apex projects ventrad between the oculo-

motor nuclei and comes into relation with the dorsal limit of the interpeduncular space. In this projection it lodges the cells which form the lateral portion of the oculomotor nucleus, while mesial to this is a nucleus of smaller cells, the *nucleus of Edinger-Westphal*.

The reticular formation is much reduced in size, and in its dorsal aspect contains no specialized nuclei. The ventral portion is now occupied by the large nucleus ruber, ventral to which is the substantia nigra which at this level is considerably decreased in its transverse and dorso-ventral diameters.

WHITE MATTER OF THE TEGMENTUM. In the white matter of the tegmentum the fasciculus longitudinalis posterior still occupies a position ventro-lateral to the nucleus oculomotorius. The fibers of the superior cerebellar peduncle form a capsule about the mesial, dorsal and partially about the lateral surface of the red nucleus. Lateral to the red nucleus is the mesial fillet in whose dorsal extremity are incorporated the fibers of the spino-thalamic tract. The central tegmental tract has come into close relation with the lateral aspects of the nucleus oculomotorius and is much reduced in size. The tract gives the impression that it either takes origin or ends in the mesencephalon.

WHITE MATTER IN THE BASIS MESENCEPHALI. The basis mesencephali consists, as in the lower section, entirely of white matter and is made up of the three groups already described. A small representation of the pes lemnisci superficialis is situated dorsal to the fronto-cerebellar tract in relation with the margin of the interpeduncular space.

EMERGENT ROOT FIBERS CONNECTED WITH THE MESENCEPHALON. At this level the emergent fibers of the oculomotor nerve still make their way from the nucleus to the oculomotor sulcus. Most of these fibers are confined to a position mesial to the red nucleus, and only a few of them pass through the substance of the nucleus.

Gray Matter and Nuclei of the Mesencephalon of Especial Importance. The cortex of the superior and inferior colliculi has already been described. It remains, therefore, to consider the histological details of the nuclei in the tegmentum of the midbrain.

NUCLEI OF THE TEGMENTUM MESENCEPHALI. The nuclei of especial importance in the tegmentum are the *nucleus trochlearis*, *nucleus oculomotorius*, *nucleus of Darkschewitsch*, the *dorsal and ventral tegmental nuclei of Gudden*, the *large cell nuclei of the raphé*, the *red nucleus*, the *ganglion interpedunculare of Ganzer* and the *substantia nigra of Soemmering*.

The *nucleus trochlearis* is exclusively motor in type and innervates the superior oblique muscle of the eye. It is situated at the transverse intercollicular sulcus in the ventral portion of the gray matter. It measures 2 mm. in length. Its cells are all of the motor type, being large pyramidal stichochromes. This nucleus is connected by means of dendrites with the aberrant pyramidal contingent from both the pes lemnisci superficialis and pes lemnisci profundus. It is also in connection by means of the fasciculus longitudinalis posterior with the nucleus of Deiters, the superior olive,

the nucleus of the sixth and third cranial nerves. The axones from the nucleus enter their emergent course by passing caudally and dorsally through the tegmentum to undergo complete decussation in the superior medullary velum.

The *nucleus oculomotorius*, or common oculomotor nucleus, is exclusively motor in type and situated in the central gray matter beneath the superior colliculus. It measures 6 to 8 mm. in length and is separated at its caudal extremity from the nucleus of the fourth nerve by a small interval. The nucleus consists of several distinct groups of cells: (a) The *central nucleus* forms a central core and is an unpaired nucleus. (b) The *medial nucleus* is a collection of cells situated between the two chief or lateral nuclei at their

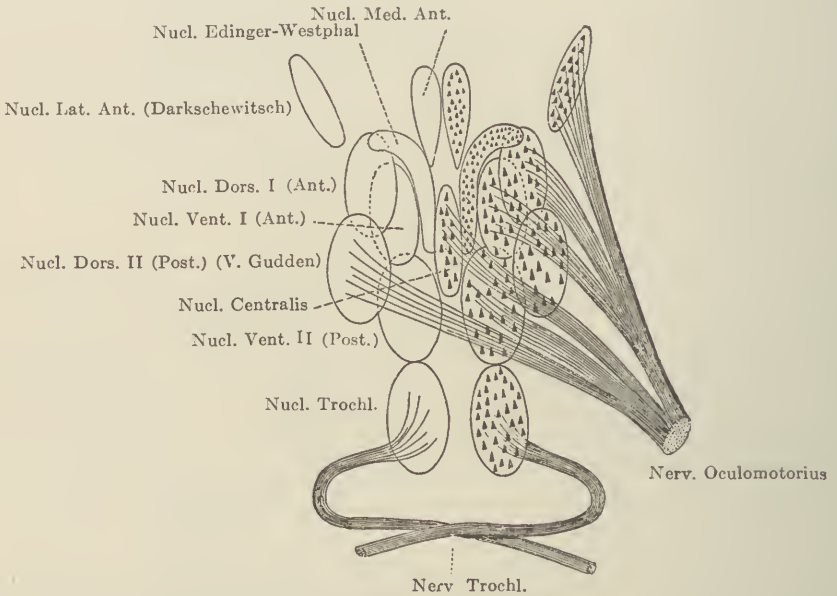


FIG. 363.—Diagram of the groups of cells forming the nuclei of the third and fourth nerves. The fibers from the nucleus of Darkschewitsch to the oculomotor nerve are doubtful. (*Perlier.*)

cephalic extremity. (c) The chief or *lateral nuclei* are paired and divisible into a ventral and dorsal portion, the significance of which depends upon the fact that the fibers arising in the ventral portion undergo complete decussation before emerging, while the fibers arising in the dorsal portion remain uncrossed throughout their entire course. (d) The *nucleus of Edinger-Westphal* is situated between the lateral nuclei near their cephalic extremity in a position somewhat dorsal to the medial nucleus. (e) The *nucleus of Darkschewitsch* is situated lateral and somewhat ventral to the cephalic extremity of the chief nucleus. It is questionable whether this nucleus contributes fibers to the oculomotor nerve as was originally thought to be the case by *Perlier*.

Segmentation of the Oculomotor Nucleus. A certain degree of segmentation has been presumed to exist in the oculomotor nucleus. Such segmenta-

tion of the nucleus was first suggested by Hensen and Voelckers, according to whose investigations it is divisible into segments from its cephalic to its caudal extremities, as follows: (1) Segment for the ciliary muscles; (2) segment for the sphincter iridis; (3) segment for the internal rectus muscle; (4) segment for the superior rectus muscle; (5) segment for the levator palpebræ muscle; (6) segment for the inferior rectus muscle; (7) segment for the inferior oblique muscle.

Cajal, however, is inclined to change the order of this segmental allocation in the oculomotor nucleus and believes that the first segment controls the superior rectus; the second, the levator palpebræ; the third, the intrinsic smooth muscles of the eyeballs; the fourth, the rectus inferior, and the fifth, the rectus internus.

More recent work by Tsuchida seems to call into question any such exact segmental localization in the oculomotor nucleus. It seems to indicate that the muscles of the eyeball receive their innervation in a more or less diffuse manner from the several cell groups in the nuclei. Clinical observation, however, is in favor of a certain degree of segmentation in this nucleus, and many observations lend support to the original conception of Hensen and Voelckers.

The function of the nucleus of Edinger-Westphal is still considerably in doubt, although it is generally conceived to be related to the innervation of the ciliary muscle and sphincter iridis.

The nucleus of Darkschewitsch, in all probability, has no direct connection with the oculomotor innervation.

The cells in the oculomotor nucleus are all of the large motor type, triangular in form, and with small centrally placed nuclei. The cells in the central and medial nucleus consist of medium sized elements, while the cells in the nucleus of Edinger-Westphal are all of the small and medium sized stellate variety. The oculomotor nucleus is probably connected with the inferior frontal convolutions slightly in front of the central fissure. Its connections are established by means of the aberrant pyramidal fibers through the subthalamic contingent and also through the peduncular contingents contained in the pes lemniscus profundus and pes lemniscus superficialis

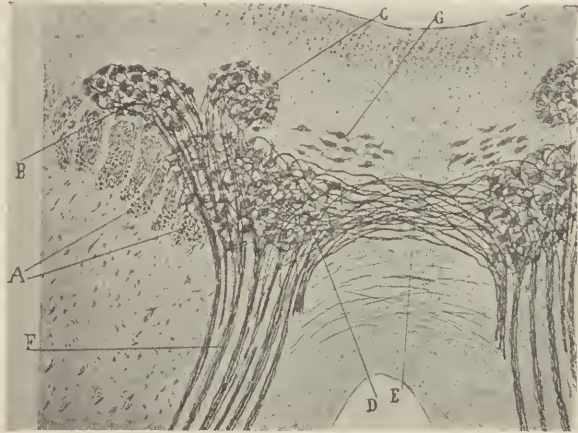


FIG. 364.—Frontal section of the midbrain at the level of the oculomotor nucleus; human fetus of 7 weeks. Silver nitrate reduction. (Cajal.)

A—Posterior longitudinal fasciculus. B—Lateral cellular group of the oculomotor nucleus. C—Superior cellular group of the oculomotor nucleus. D—Ventral or principal cellular group of the oculomotor nucleus. E—Transverse commissure formed by the decussating fibers coming from the principal cellular group. F—Roots of the oculomotor nucleus.

It is indirectly in connection with the visual cortex by the fibers which pass from the occipital lobe through the optic radiation and the superior brachium to the superior colliculi and by means of the posterior longitudinal fasciculus with the nuclei of the fourth and sixth cranial nerves. This fasciculus also affords connection with the vestibular nucleus of Deiters and probably with the superior olivary nucleus and nucleus facialis.

The connection with the motor cortex of the cerebral hemispheres by the aberrant pyramidal fibers is important because it supplies volitional control to oculogyric movements in all directions.

The connection of the oculomotor nucleus with the visual cortex of the hemispheres serves to fix the eye in maintaining visual attention.

The connection of the oculomotor nucleus by means of the fasciculus longitudinalis posterior correlates the action of all the oculomotor nuclei. It also serves to bring the ocular muscles under the influence of the cerebellum and of Deiters' nucleus. It furnishes a connection with the auditory nuclei so that stimuli from the ear may be coordinated with the movements of the eyeball. Its connection with the facial nucleus provides for the reflex stimulation of the corrugator supercilii muscle and muscles of the eyelids.

The Mesencephalic Nucleus of the Trigeminal Nerve. This nucleus is the prolongation of the upper nucleus of the fifth nerve, which consists of a small number of globular cells situated at the external lateral margin of the central gray matter in close connection with the mesencephalic root of the fifth nerve. The nucleus, as well as the mesencephalic root of the nerve, gradually becomes smaller and finally disappears at the superior extremity of the mesencephalon.

Nucleus Tegmenti Dorsalis of Gudden. This nucleus is situated in the central gray matter dorsal to the nucleus trochlearis. It has a cephalic extension, the *nucleus dorsalis accessorius*, which maintains a similar relation to the nucleus of the third nerve. The cells of this nucleus are small and ovoid or triangular in form and possess two or three dendrites. The axones pass to the fasciculus longitudinalis dorsalis of Schütz, while the dendrites are in communication with the interpeduncular ganglion of Ganser by means of the interpeduncular tegmental fasciculus. This nucleus establishes the connections of an ancient motor pathway associated with the olfactory sphere. It undoubtedly made possible the transference of impulses received by the olfactory portions of the brain to the bulb and spinal cord, thus activating movements in the interest of securing food.

Nucleus Tegmenti Ventralis of Gudden. This nuclear collection of cells is situated in the reticular formation lateral to the fasciculus longitudinalis posterior and ventral to the nucleus trochlearis. It consists of medium sized and stellate cells. The axones extend to the neighboring white matter and possibly enter the fasciculus longitudinalis posterior. Its functional significance is not known.

Nucleus Magnocellularis of the Raphé. This nucleus is situated in the midline near the raphé and beneath the nucleus trochlearis. It is made up

of large cells in many respects resembling motor elements. The axones appear to enter the fasciculus longitudinalis posterior. Its exact functions are not clearly understood.

Nucleus Ruber. This is the largest nucleus of the midbrain. It is mainly motor in type. It is situated in the tegmentum underlying the superior colliculus and extends for a considerable distance into the next division of the brain where its head occupies a position in the subthalamic region. This is the case in man. In some of the lower mammals its extension into the midbrain is more limited. It is irregularly ovoid in shape with its base pressed against the decussated bundles of the superior cerebellar peduncle and its apex projecting into the subthalamic region of the diencephalon. The fibers of the the cerebellar peduncles not only enter this nucleus, but also form a fairly dense capsule about its ventro-mesial and dorsal aspects. The nucleus consists of three types of cells: (a) The large multipolar stichochrome cells with a large vesicular nucleus and small nucleolus. The axones from these cells undergo a complete crossing in the ventral tegmental decussation of Forel, and from this point participate in the formation of the rubrospinal tract (fasciculus of Monakow). (b) Medium sized cells, also motor in type, whose axones enter the decussation of Forel and pass into the rubrospinal tract. (c) Small cells of Golgi type II, which seem to serve in the usual capacity of such cellular elements.

The red nucleus receives collaterals and terminals from the superior cerebellar peduncle, from the optic reflex path, from the fasciculus of Gudden, from the mesial fillet, from the reticular formation, from the fasciculus longitudinalis posterior, and perhaps from the cerebral cortex. Its chief functional importance is in the fact that it brings the cerebellum and the corpus striatum into direct control over the somatic muscles of the body.

The Interpeduncular Ganglion of Ganser. This nucleus is situated in the interpeduncular space ventral to the decussation of Meynert. The cells in it are of two varieties—the large stellate cells and the small vesicular elements. It receives fibers from the fasciculus retroflexus of Meynert, which thus establishes connection with the habenular ganglion of the thalamus. Its efferent fibers constitute the *interpeduncular tegmental fasciculus* and terminate in the dorsal tegmental nucleus of Gudden. This ganglion has already been referred to as part of the ancient motor pathway connected with the olfactory sphere.

The Substantia Nigra of Soemmering. This extensive mass of gray matter is situated between the ventral aspect of the mesial fillet and the basis mesencephali. It consists of two zones, the more inferior of which contains but few nerve cells but is rich in protoplasmic processes and a plexus of fibers passing through it. The superior or marginal zone contains many cells. The cells in this layer are relatively large, measuring from 8 to 24 micra in diameter, and contain a dark-colored pigment which gives the area a brownish appearance. The axis cylinders of these cells are thick and leave the substantia nigra as a collected bundle sometimes spoken of as the

peduncle of the substantia nigra. According to some authorities (Kolliker) the peduncle of the substantia nigra divides into two branches, one of which is lost in the lateral region of the midbrain, the other serving to reinforce the median fillet. Bechterew expresses the view that the peduncle of the substantia nigra becomes part of the cerebral peduncle and ascends to the corpus striatum. The significance of this large mass of gray matter in the midbrain is at present unknown.

Tracts of Especial Importance in the Tegmentum Mesencephali.
The Superior Cerebellar Peduncle. This massive bundle of fibers arises in the dentate nucleus of the cerebellum and proceeds into the midbrain where it undergoes a complete decussation and ends, in large part, in the red nucleus. Some of its fibers, however, pass forward into the optic thalamus, establishing in this way a cerebello-thalamic connection. This tract serves to introduce the cerebellar influence over muscular activity. Nerve impulses derived from the cerebellum are distributed to the ipsilateral portions of the body musculature. Although the superior cerebellar peduncle undergoes decussation in the midbrain, the axones derived from the red nucleus immediately recross in the ventral tegmental decussation of Forel. This double crossing in the cerebello-rubro-spinal pathways establishes the ipsilateral control of the cerebellum.

The Fasciculus Longitudinalis Posterior. This fasciculus is made up of ascending and descending axones. The ascending fibers come from the following sources: (a) Deiters' nucleus, by means of which connection is established between the sixth, fourth and third oculomotor nerves, bringing them under the direct influence of the cerebellum and equilibratory mechanism. (b) Fibers from the sensory nucleus of the trigeminus nerve correlating the movements of the eye with sensory impressions received by the head and especially upon the conjunctiva. These fibers provide for reflex movements. (c) Fibers from cells in the ventral gray column of the spinal cord. (d) Fibers from cells in the reticular formation of the bulb, pons and midbrain. Some of the fibers of the fasciculus longitudinalis posterior are said to continue into the region of the hypothalamus. (e) Fibers from the sixth and fourth cranial nerve nuclei. (f) The nucleus of Darkschewitsch also contributes some descending fibers to this fasciculus.

The descending fibers of the fasciculus longitudinalis posterior are largely derived from the *nucleus interstitialis* of Cajal, which is a collection of cells situated mesial to the cephalic extremity of the red nucleus. Other descending axones also may be contributed by the nucleus oculomotorius and the nucleus trochlearis. The fasciculus longitudinalis posterior is essentially a connecting link between the three oculomotor nuclei in order to coordinate their action.

The Rubro-Spinal Tract (Fasciculus Aberrans of Monakow). This tract is formed by fibers arising in the cells of the red nucleus, which decussate in the ventral tegmental decussation of Forel. They descend into the pons and medulla and then pass into the lateral white column of the spinal cord. The tract constitutes the extrapyramidal system of motor fibers. It

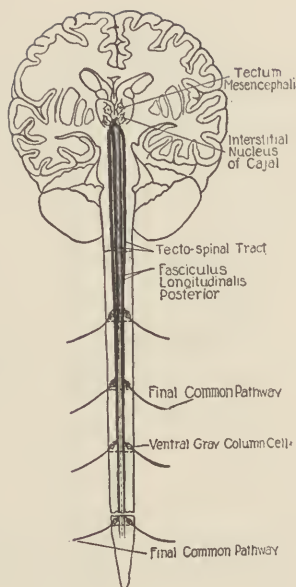
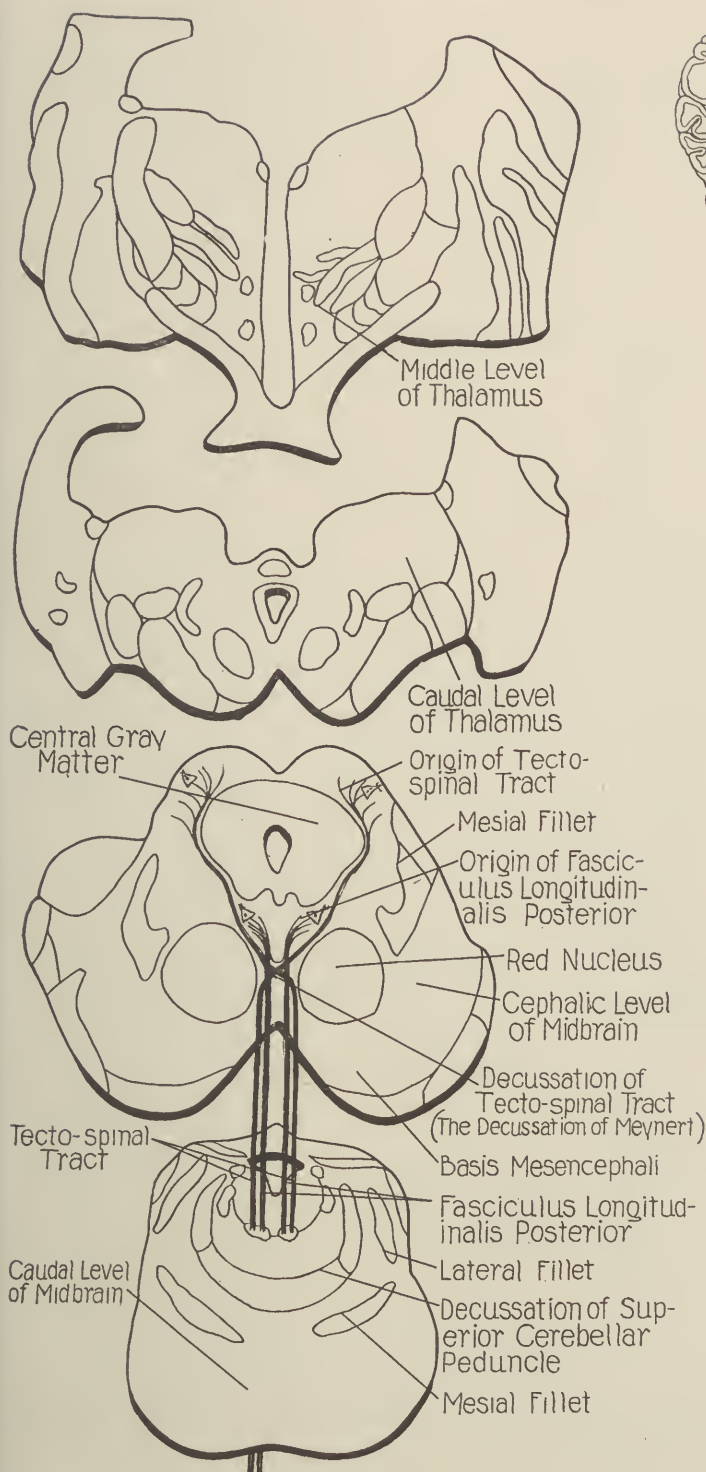


FIG. 365.—The fasciculus longitudinalis posterior and the tecto-spinal tract in their passage through the midbrain. The tracts serve for the conduction of impulses from the tectum of the midbrain and the interstitial nucleus of Cajal to the ventral gray column cells of the spinal cord and between the nuclei of the oculomotor mechanism. They function as part of the protective mechanism against excessive light impulses and other possible injuries. The fasciculus longitudinalis posterior contains both ascending and descending fibers.

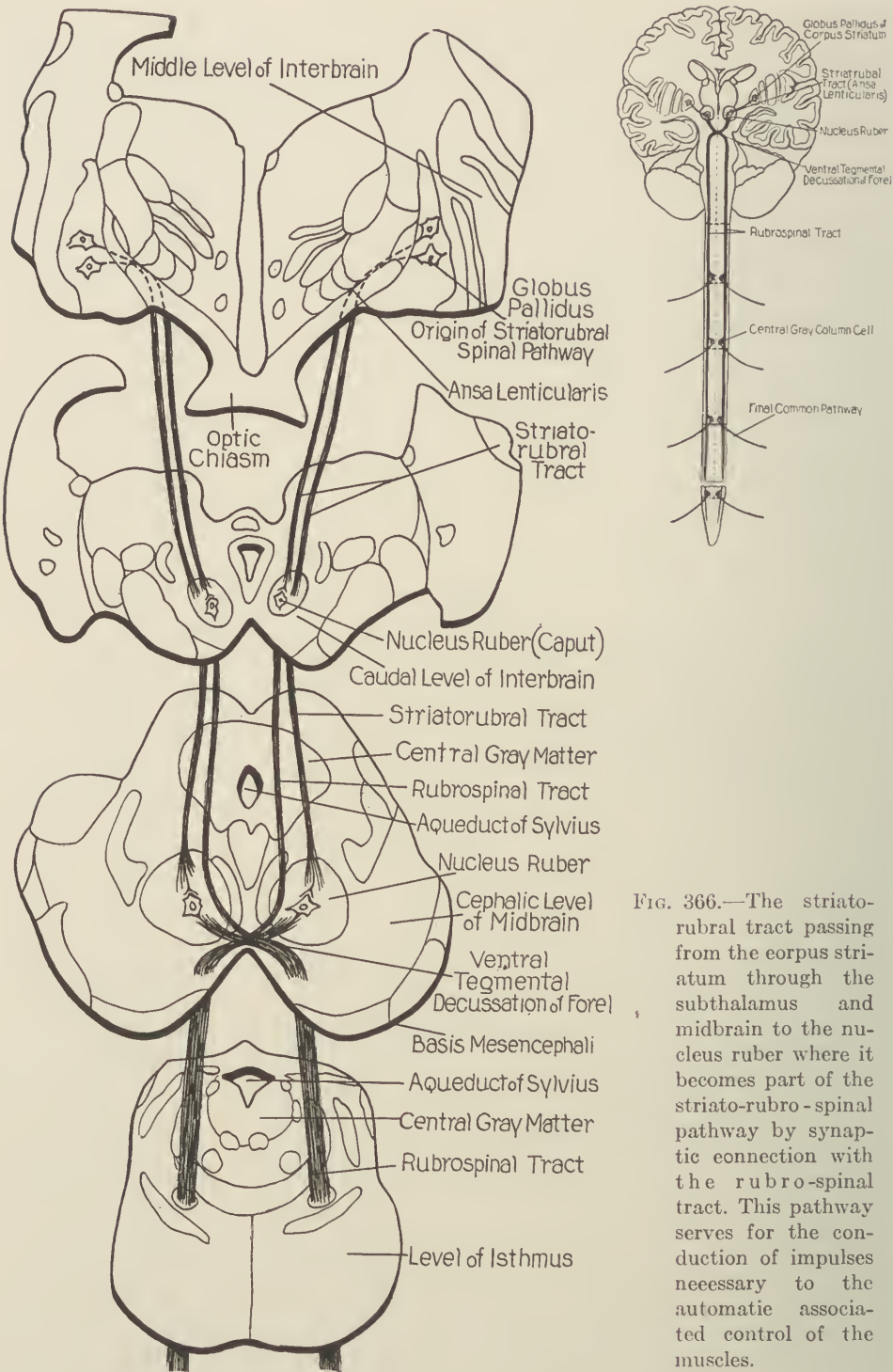


FIG. 366.—The striatorubral tract passing from the corpus striatum through the subthalamus and midbrain to the nucleus ruber where it becomes part of the striato-rubro-spinal pathway by synaptic connection with the rubro-spinal tract. This pathway serves for the automatic associated control of the muscles.

serves the dual function of bringing synergic and automatic associated control to the final common pathway.

The Tecto-spinal Tract. This tract arises in the superior colliculi and passes by way of the internal arciform fibers to the dorsal tegmental decussation of Meynert. From this point it forms a compact bundle which descends in relation with the posterior longitudinal fasciculus through the pons and medulla into the ventral white column of the spinal cord. It serves to activate reflex movements in the facial musculature, in the arms, trunk and neck, in response to light impressions.

The Fasciculus Longitudinalis Dorsalis of Schütz. This tract descends in the central gray matter close to the aqueduct of Sylvius. It arises in the *dorsal tegmental nucleus* of Gudden and may be traced through the pons and medulla into the spinal cord. It probably represents an ancient motor pathway connected with the olfactory lobe.

The Mesial and Lateral Fillets. The mesial fillet passes through the tegmentum of the midbrain in close association with the lateral fillet. The ascending portion of the mesial fillet is associated with the conduction of somesthetic sensory impulses, while the lateral fillet is part of the pathway for the conduction of auditory impulses. In the more cephalic portion of the midbrain the mesial fillet becomes associated with the spino-thalamic tract which serves for the conduction of pain-temperature stimuli.

Descending fibers are also found in the mesial fillet. These axones have become secondarily associated with the fillet and have gained this affiliation by a transference from their original position in the basis mesencephali. They are the subthalamic and peduncular contingents of the aberrant pyramidal system. They serve to convey motor impulses which innervate the motor nuclei of the cranial nerves.

The Brachium Inferius. This fasciculus occupies a peripheral position for a short distance in the midbrain and serves to connect the inferior colliculus with the mesial geniculate body.

The Ventral Spino-Cerebellar Tract. This tract makes a brief course along the lateral margin of the midbrain, turns obliquely backward, traverses the superior cerebellar peduncle and thus enters the inferior vermis of the cerebellum.

The Tractus Peduncularis Transversus. This is a compact bundle of fibers occasionally observed in man, but fairly constant in other mammals. It appears on the lateral aspect of the midbrain ventral to the superior colliculus and passes around the cerebral peduncles crossing in such a way as to reach the mesial surface of the peduncle, where it passes between emergent fibers of the third nerve and the corpus mammillare. It penetrates the midbrain between the substantia nigra and formatio reticularis. The origin and ending of its fibers are still obscure.

White Matter of the Basis Mesencephali. The entire basis of the midbrain consists of fibers which constitute the cerebral peduncles. These peduncles are made up of three distinct groups of fasciculi, the most mesial of which is the frontal pallio-pontile tract. It connects the frontal areas

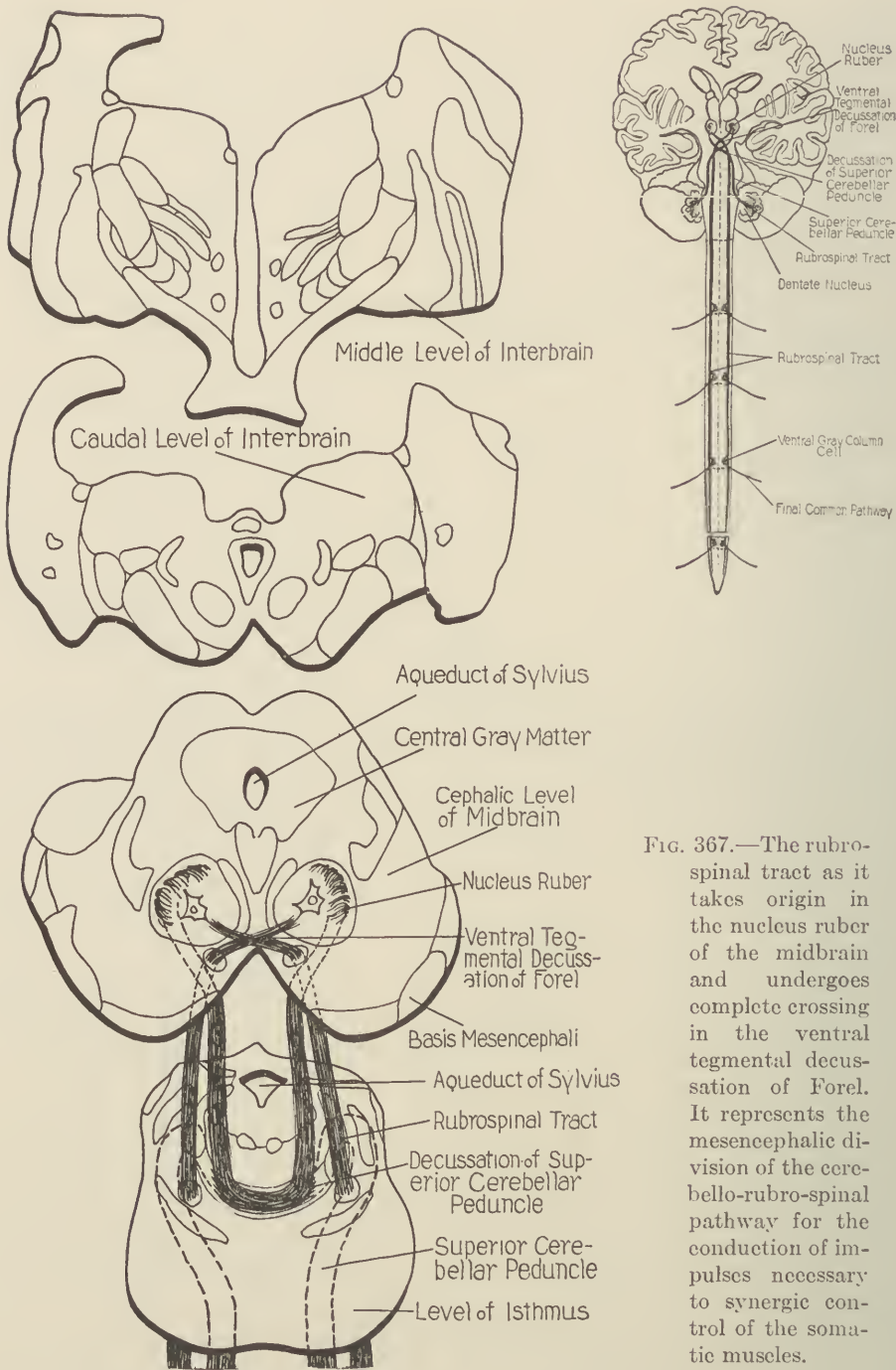


FIG. 367.—The rubrospinal tract as it takes origin in the nucleus ruber of the midbrain and undergoes complete crossing in the ventral tegmental decussation of Forel. It represents the mesencephalic division of the cerebello-rubro-spinal pathway for the conduction of impulses necessary to synergic control of the somatic muscles.

of the cerebral cortex with the opposite hemisphere of the cerebellum. The most lateral group of fibers in the peduncle constitutes the occipito-parieto-temporal pallio-pontile tract and serves to connect the occipital (visual), parietal (somesthetic), temporal (auditory) areas of the cerebral cortex with the cerebellar hemisphere of the opposite side. The intermediate fasciculus comprises the cortico-spinal and cortico-nuclear or pyramidal system of fibers. It represents the connection between the motor area of the cerebral cortex and the ventral gray column of the opposite side. Many of the cortico-nuclear fibers which belong to the aberrant pyramidal system pass from the cerebral peduncle through or around the substantia nigra to join the mesial fillet. These fibers constitute the pes lemniscus superficialis and the pes lemniscus profundus. They provide some of the fibers which establish the connection between the motor cortex of the cerebral hemisphere and the cranial nerve nuclei.

CHAPTER XXX

THE MIDBRAIN

THE FUNCTIONS AND PRINCIPAL SYNDROMES OF THE MESENCEPHALON

FUNCTIONS OF THE GRAY MATTER OF THE MESENCEPHALON

Many of the activities of the midbrain which have already been outlined may now be considered in their specific relations to the gray and white matter. The midbrain in its immediate influences is confined largely to somatic motor and sensory functions; its planchnic activities have but slight representation. In this respect the mesencephalon differs from the pons and the medulla which are chiefly concerned in the visceral functions.

Functions of the Tectum of the Midbrain. The functions of the roof of the midbrain have in part been discussed. The inferior colliculus in man serves as a relay station for impulses making their way from the auditory receptors to the cortex. In this relay many of the axones of the secondary auditory tracts find actual synapsis, while others pass directly by the collicular cells through the inferior brachium to the mesial geniculate body.

The relation of the superior colliculus to vision in man has been greatly reduced in its importance, due to the telencephalization of the visual sense. The superior colliculus, however, does serve as a relay for *light fibers*, by means of which certain reflexes of the intrinsic muscles of the eye are brought into play. These are known as the *light reflexes*.

THE DIRECT LIGHT REFLEX. The direct light reflex is elicited by throwing a ray of light upon the retina through the pupil. It manifests itself in an immediate contraction of the sphincter iridis, which causes a reduction in the size of the pupillary aperture. This reflex depends upon an afferent arm consisting of the retina, optic nerve, optic tract and the light fibers terminating in the superior colliculus. From this point colliculo-oculomotor fibers establish the reflex connection with the oculomotor nucleus which transmits the motor impulse to the sphincter iridis, thus producing a contraction of the pupil. The direct light reflex regulates the illumination of the retina and is active when the degree of light is such as to require but a small aperture for its admittance. In cases of excessive stimulation by light, the pupil may be reduced approximately to a pin-point.

THE CONSensual LIGHT REFLEX. The consensual light reflex is elicited by stimulation of one eye which produces a reflex response in the opposite pupil. This reaction is due to the fact that many of the fibers which arise in the superior colliculus cross by way of the superior collicular commissure to the opposite side and thus come into relation with the contralateral oculomotor nucleus.

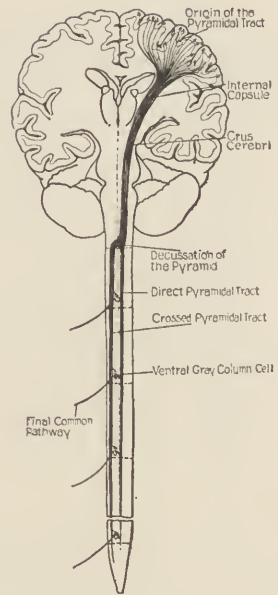
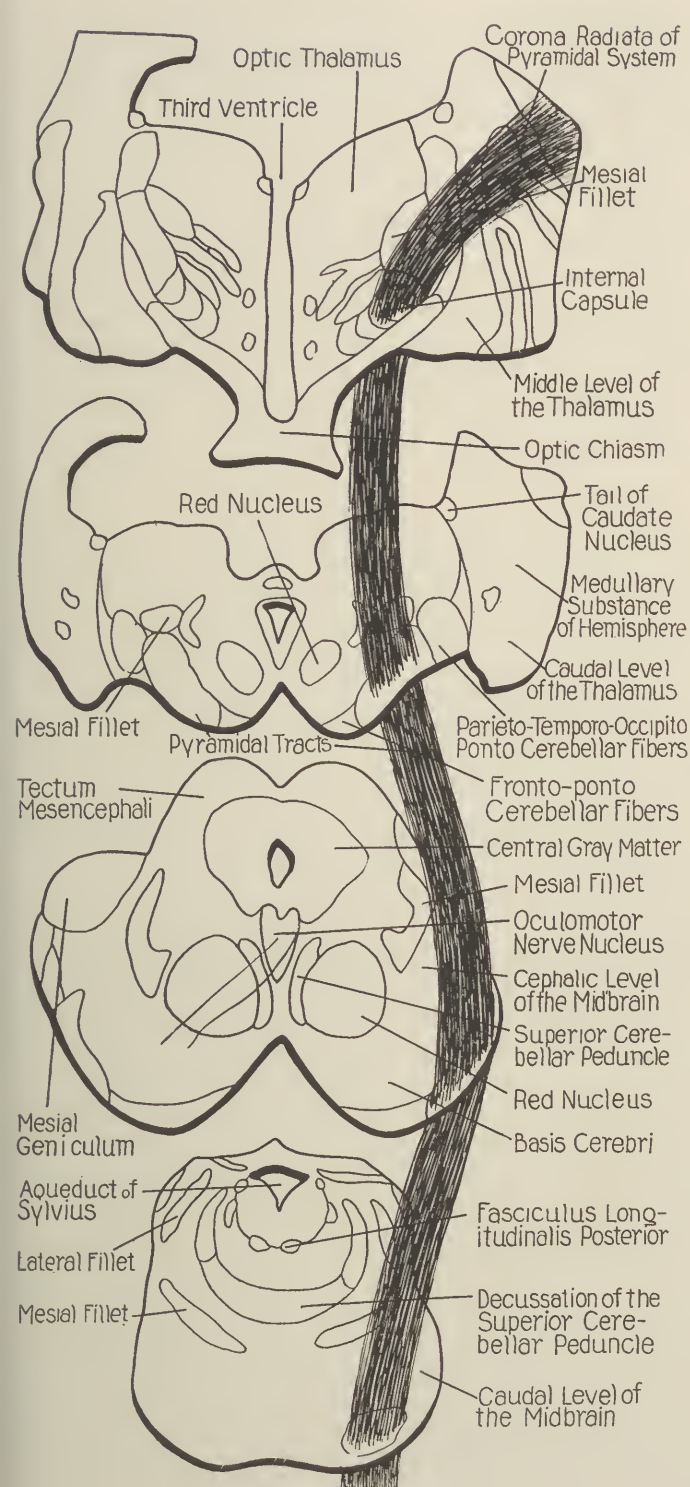


FIG. 368.—The pyramidal tract as it passes through the internal capsule and the midbrain on its way from the giant cells of the precentral cortex to the ventral gray column motor cells of the spinal cord. This tract serves for the conduction of impulses of volitional control over the somatic musculature.

THE EMERGENCY LIGHT REFLEX. A third type of light reflex mediated through the superior colliculus has as its object the protection of the retina against extreme or excessive illumination. Excessive stimulation of the retina leads reflexly to a contraction of the pupils, a closure of the eyelids, and a lowering of the eyebrows. It may, in fact, be combined with a contraction of the entire face, a bending of the head forward, and a drawing of the forearm across the eyes. This reflex depends upon the light fibers which end in the superior colliculus. From this center excessive light stimuli pass to the facial nucleus as well as to centers for the neck and arm muscles in the spinal cord by means of the tecto-bulbar and tecto-spinal tracts. Protective movements of the eyelids, eyebrows, head and arms are thus activated. This mechanism undoubtedly serves also as a protection against objects suddenly approaching the eye, and a reflex reaction occurs in response to such stimulation similar to that caused by excessive illumination.

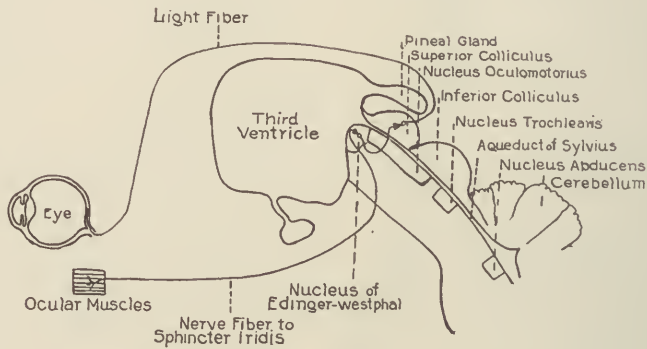


FIG. 369.—Diagram representing the pupillary light reflex.

ACCOMMODATION AND CONVERGENCE REFLEXES. These reflexes are elicited by having the subject gaze at a distant object (more than thirty feet away) and then suddenly adjust his vision to an object several inches from the eyes. In consequence both pupils contract as in the case of the light reflex. The reaction depends upon a stimulus reaching the visual cortex by way of the optic nerve and then mediating appropriate impulses to cause contraction of both pupils in the interest of concentrating visual impressions upon the macula. It is possible that this reflex may require a more complex arc, which ultimately depends upon the visual cortex, before the impulses are translated into reflex action. The convergence of the eyeballs due to focusing upon a nearby object determines a similar reflex.

OCULO-CEPHALO-GYRIC REFLEX. The superior colliculus acts as the principal relay in a highly complex reflex whose purpose is to direct the movements of the eye, the head and the body in the interest of visual attention. The efferent impulses for this reflex action arise in certain cells of the visual cortex whose axones make their way through the optic radiation into the retrolenticular portion of the internal capsule and thus to the superior colliculus. Here they reach the collicular cells and stimulate impulses

which pass to the pons, bulb and spinal cord. The purpose of these impulses is to activate such movements as are necessary to maintain the gaze of the eyes in a fixed position. This is a connection of which little is known at the present time. Certain clinical and anatomical facts point conclusively to its existence. It differs from the volitional control of the eyes and head in that it does not produce voluntary eye movements in any direction; but once the gaze is fixed upon an object, the ocular muscles determine such movements of the eyes as are necessary to keep the object in visual attention. For example, a patient may be unable to look to the left in order to bring an object into view; yet if he is told to fix his gaze on some object held before him, and his head is turned to the right, he may still be able to keep his gaze fixed on the object in spite of the movement of the head. This condition requires a movement of the eyes to the left to counteract the movement of the head to the right. The patient is unable to make such

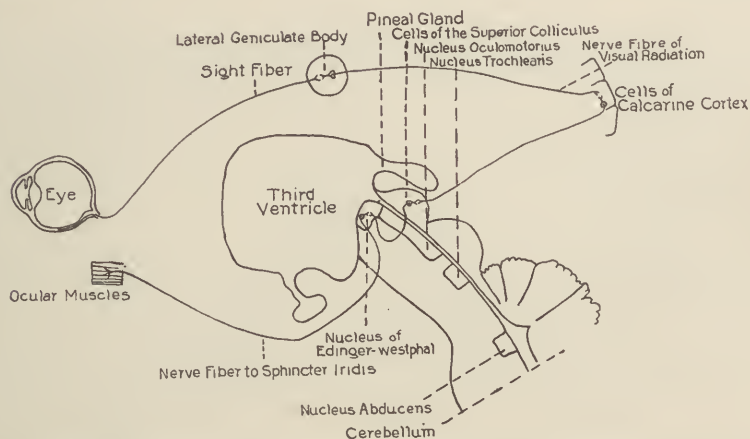


FIG. 370.—Diagram representing the accommodation and convergence pupillary reflex.

eye movements voluntarily, but is able to do so reflexly in order to hold the object in view.

In the main, the superior colliculus of the midbrain in man serves for the relatively simple reflex correlations connected with visual sense. All of the higher synthetic processes of vision have been delegated to the occipital lobe of the cerebral cortex.

Functions of the Tegmentum of the Midbrain. Certain nuclei in the central gray matter call for special attention with reference to the functions which they perform:

The *nucleus trochlearis* sends its fibers to the superior oblique muscle and innervates the muscle which produces internal rotation and convergence of the eyeball. The result of this internal rotation and convergence serves to divert the visual axes of the two eyes out of their usual parallel for the purposes of acts in near vision such as reading. This action facilitates the focusing of the macula of both retinae upon a common point relatively

near the eye. Paralysis of this nerve leads to double vision in reading and in looking at objects near at hand. It does not affect the vision in other positions.

The nucleus trochlearis has intersegmental and suprasegmental connections. The intersegmental connection is established by the fasciculus longitudinalis posterior and serves to associate this nucleus with the other two nuclei of the oculomotor mechanism, so that there is a complete harmony in the cooperation of all the muscles of the eyeball. Lack of such harmony by injuries to the posterior longitudinal fasciculus produces a dissociation of the eye movements. The trochlear nucleus also has a suprasegmental connection by means of fibers from the red nucleus which bring to it synergic and automatic associated control. Volitional control is maintained through the peduncular contingent of the aberrant pyramidal system. Another important suprasegmental connection seems probable by reason of the

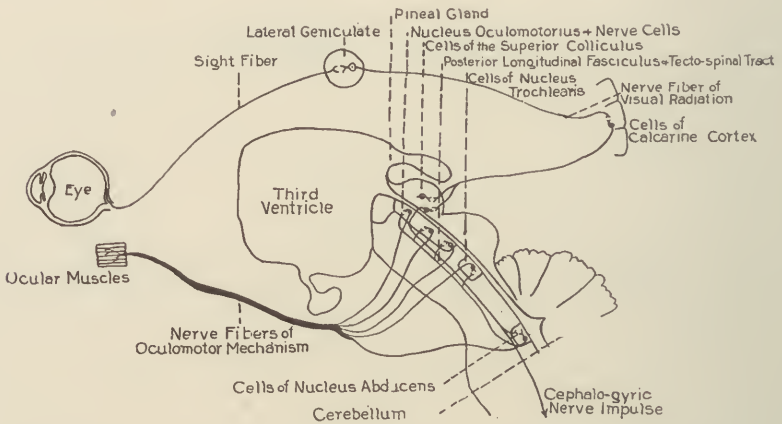


FIG. 371.—Diagram representing the oculo-cephalo-gyric reflex.

fact that there are certain acts which do not lie within the volitional sphere of eye movements; for example, the act of convergence by means of the contraction of the two superior oblique muscles as seen in the eyes when looking at the tip of the finger held close to the end of the nose or in the attempt to look at the end of the nose. Without first fixing visual attention upon some object, it is impossible to produce any act resembling convergence of the eyeballs. The fact that in the blind convergence cannot be made as an act of the will suggests that visual attention is essential to the production of these movements. It is reasonable to presume, therefore, that the act of convergence necessary to near vision is in large part accomplished through a connection of the visual cortex with the superior colliculus. Although this represents a suprasegmental connection of great importance, it does not, strictly speaking, belong to the sphere of volitional control. This reaction may be referred to as the *convergence reflex of visual attention*.

The *nucleus oculomotorius communis* supplies the intrinsic muscles of the eye, that is, the sphincter iridis and the ciliary muscles. It also supplies the extrinsic muscles of the eyeball with two exceptions; namely, the external rectus, which is supplied by the abducens nerve, and the superior oblique, which is supplied by the trochlear nerve. The muscles of the eyeball supplied by the oculomotor nerve are: the superior rectus, the internal rectus, the inferior rectus and the inferior oblique.

One of the muscles of the upper eyelid is also supplied by this nerve, the levator palpebræ superioris.

The *Edinger-Westphal nucleus* supplies nerve fibers to the ciliary muscle and the muscle of the sphincter iridis. It is connected directly with the superior colliculus and thus mediates both the direct and consensual light reflexes and is essential to the reflexes of accommodation and convergence.

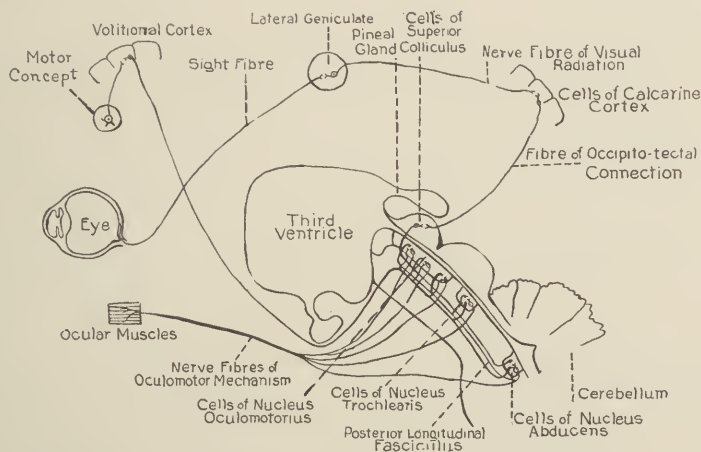


FIG. 372.—Diagram representing the voluntary and fixation ocular movements.

The Action of the Oculomotor Nucleus in the Control of Eye Movements. The nucleus of the third nerve holds idiodynamic control over the majority of the muscles of the eyeball. It receives influences from many sources. Acting as the final common pathway to most of the eye muscles, it regulates the complicated associated movements of the two eyes. The nucleus has intrasegmental, intersegmental and suprasegmental connections.

INTERSEGMENTAL CONNECTIONS OF THE OCULOMOTOR NUCLEUS FOR ASSOCIATED REFLEXES REQUIRING THE COMBINATION OF SEVERAL SEGMENTS.

The significance of the intersegmental connections of the oculomotor nucleus has already been considered in the discussion of the light, accommodation and convergence reflexes.

Auditory Oculomotor Associated Reflex. This reflex depends upon auditory stimuli received by the internal ear and transmitted from the pons to the midbrain by the lateral fillet, collaterals from which terminate in the inferior colliculus. A colliculo-oculomotor set of fibers reaches the third

nerve nucleus, from which fibers pass to the muscles of the eyeball and produce movements directing the eyes toward a sound above or below the level of the eyes. Lateral movements of the eyes to the right and left in response to sounds are determined by a reflex connection between the superior olive and the nucleus of the sixth nerve.

Conjunctival Oculomotor Associated Reflex. This reflex is elicited by stimulation of the conjunctiva of either eyeball, and manifests itself by a rolling upward of the eye. The afferent arm of this reflex is in the trigeminal nerve from the conjunctiva through the Gasserian ganglion by way of the dorsal root, thence by ascending secondary neurones to the oculomotor nucleus. From this point collaterals or intercalary neurones make their way to the nucleus oculomotorius and call into action a section of the nucleus which produces contraction of the superior rectus with a consequent upward movement of the eyeball. This is an associated reflex in the interest of protecting the more delicate structures situated in relation with the cornea.

Interocular Associated Reflexes. These associated reflexes are accomplished by means of the fasciculus longitudinalis posterior which connects all three of the nuclei concerned in the oculomotor movements, namely, the third, fourth and sixth cranial nuclei. In this grouping the sixth nerve is presumed to be the pace-maker; and impulses starting in this nucleus proceed by way of the fasciculus longitudinalis posterior to the fourth and third nuclei, thus stimulating responses appropriate to produce the necessary associated interocular reflexes. A lesion of the posterior longitudinal fasciculus causes dissociation of the eye movements.

Oculofacial Associated Reflex. This reflex is elicited by stimulation of the conjunctiva over the cornea and manifests itself as an upward movement of the eyeball together with the closure of the eyelid and contraction of the facial muscles about the eye. The afferent arm of this reflex is provided by the ophthalmic division of the fifth nerve to the Gasserian ganglion and thence to the substantia gelatinosa of Rolando, from which point ascending neurones complete the connection with the fasciculus longitudinalis posterior. This connection brings into associated action the nuclei of the third and seventh nerves, which transmit motor impulses to the muscles of the eyeball and eyelid.

Vestibulo-Ocular Associated Reflex. This reflex is elicited by electrical, thermal and mechanical stimulation of the receptors in the vestibule of the internal ear. Such stimuli are transmitted to Deiters' nucleus by means of the vestibular division of the eighth nerve. Through synaptic connection with Deiters' nucleus the impulses are brought into relation with the sixth and third nerves, which then cooperate in the production of the reflex movements of the eyes known as nystagmus.

CONNECTIONS OF THE OCULOMOTOR NUCLEUS FOR SUPRASEGMENTAL CONTROL. The oculomotor nucleus is connected by means of the subthalamic and peduncular contingents of the aberrant pyramidal system with the motor area of the cerebral cortex. By this connection volitional

impulses are transmitted to the muscles innervated by the oculomotor nucleus. The fibers establishing volitional control over the nucleus are of two groups; a subthalamic contingent supplying divisions of the nucleus which innervate the superior and inferior recti muscles and thus determine upward and downward movements of the eyes; and a peduncular contingent which, through the sixth nerve, supplies the external rectus, and, through the third nerve, supplies the internal rectus. These two muscles cooperate in the lateral movements of the eyes. By means of these fibers of volitional control, the eyes may be moved at will in all directions, independent of or in cooperation with movements of the head. The individual may be directed to look in a certain direction at a definite object and be able to move the eyes volitionally in that direction. This type of motor control over the eye-muscles is to be distinguished from another important form of eye movement, which is in the interest of fixing the gaze, and depends mainly upon visual attention and an efferent connection with the visual cortex.

The oculomotor nucleus receives its synergic and automatic associated control by means of axones connecting it with the red nucleus which acts as an intermediary between the oculomotor nucleus and the cerebellum and also between this nucleus and the corpus striatum.

Special Nuclei of the Tegmentum. *Nucleus Mesencephalicus Trigemini.* The mesencephalic nucleus of the fifth nerve lies on the border between the central gray and the reticular formation. According to some authorities it acts as a receiving center for the sense of taste. It seems more probable, however, that this nucleus has a sensory activity related to the muscular sense for the muscles of mastication.

Nucleus Dorsalis Tegmenti of Gudden. This nucleus and its accessory nucleus form a way station in the pathway leading from the diencephalon to the pons, medulla and possibly to the spinal cord. It mediates motor impulses which are of much greater importance in the lower vertebrates than in man.

The Interpeduncular Ganglion of Ganzer. This ganglion belongs to the same system as the nucleus dorsalis tegmenti of Gudden and has a similar significance. It is vestigial or absent in man.

Certain nuclei of the reticular formation in the midbrain are of particular importance:

The Red Nucleus or Nucleus Ruber. The functional significance of the red nucleus has already been discussed in part. It serves as an intermediary in the connection between the cerebellum and brain-stem on the one hand, and the brain-stem and spinal cord on the other. It transmits the nerve impulses from the cerebellum necessary to synergic control of the muscles destined for the final common pathway. It is also in connection with the corpus striatum, and in this way conducts the impulses necessary to automatic associated control of the muscles. The details of this connection will be discussed in connection with the corpus striatum.

The Ventral Tegmental Nucleus, Nucleus of the Raphé and the Substantia Nigra. The functions of the ventral tegmental nucleus, of the large celled

nucleus of the raphé and the substantia nigra, are still so much in doubt that no satisfactory statement may be made concerning them.

THE FUNCTION OF THE WHITE MATTER OF THE MESENCEPHALON

The white matter of the tegmentum provides continuity in the ascending and descending tracts of the brain-stem, while the white matter of the basis contains descending tracts alone.

Ascending Tracts of the Tegmentum. 1. The *mesial fillet* contains the continuation cephalad of the pathway for discriminative sensibility. At this level, near its mesial extremity, it also contains some descending fibers representing aberrant pyramidal contingents which have reached it by way of the *pes lemnisci profundus* and *pes lemnisci superficialis*.

2. The *lateral fillet* and *inferior brachium* represent the continuation of the secondary auditory pathway toward the cortex.

3. The *spino-thalamic tract* is part of the pathway for the conveyance of impressions of pain and temperature sensibility.

4. The *dorsal spino-cerebellar tract* represents an accessory connection between the muscles and the cerebellum. It makes a short course through the midbrain to reach the superior cerebellar peduncle and finally the cerebellum.

5. The *mesencephalic root of the trigeminus nerve* conducts sensory impulses essential to muscular sense for the muscles of mastication.

6. The *fasciculus longitudinalis posterior* in the main serves as an inter-segmental associating system between the nuclei of the oculomotor mechanism. In it are also some descending fibers which in all probability arise in the *nucleus of Darkschewitsch*, and others from the *nucleus interstitialis* of Cajal. Their functions are not as yet understood.

7. The *superior cerebellar peduncles* ascend through the caudal portions of the midbrain to end in the red nucleus after a complete decussation. They serve to introduce the cerebellar influence over the brain-stem and spinal cord.

Descending Tracts of the Tegmentum. 1. The *rubro-spinal tract* descends in the ventro-mesial portion of the tegmentum and takes origin in cells of the red nucleus whose axones cross the midline in the ventral tegmental decussation of Forel.

2. *Aberrant pyramidal fibers* associated with the mesial fillet represent peduncular contingents of the aberrant pyramidal system.

3. The *tecto-spinal tract* arises in the superior colliculus and supplies impulses to the nuclei of the oculomotor mechanism as well as to the nuclei in the medulla controlling cephalo-gyric movements. It serves the purpose of protecting the eye by means of reflex movements in the facial muscles, the muscles of the neck and the muscles of the upper extremities. It also acts as a suprasegmental connection which effects the maintenance of ocular position for fixed gaze.

4. The *central tegmental tract* connects the oculomotor nucleus and probably the nuclei of the fourth and sixth nerves with the inferior olive, in

all probability acting to maintain associated movements between the eyes and head.

Descending Tracts in the Basis Mesencephali. Three major systems of descending tracts pass through the basis mesencephali. These consist

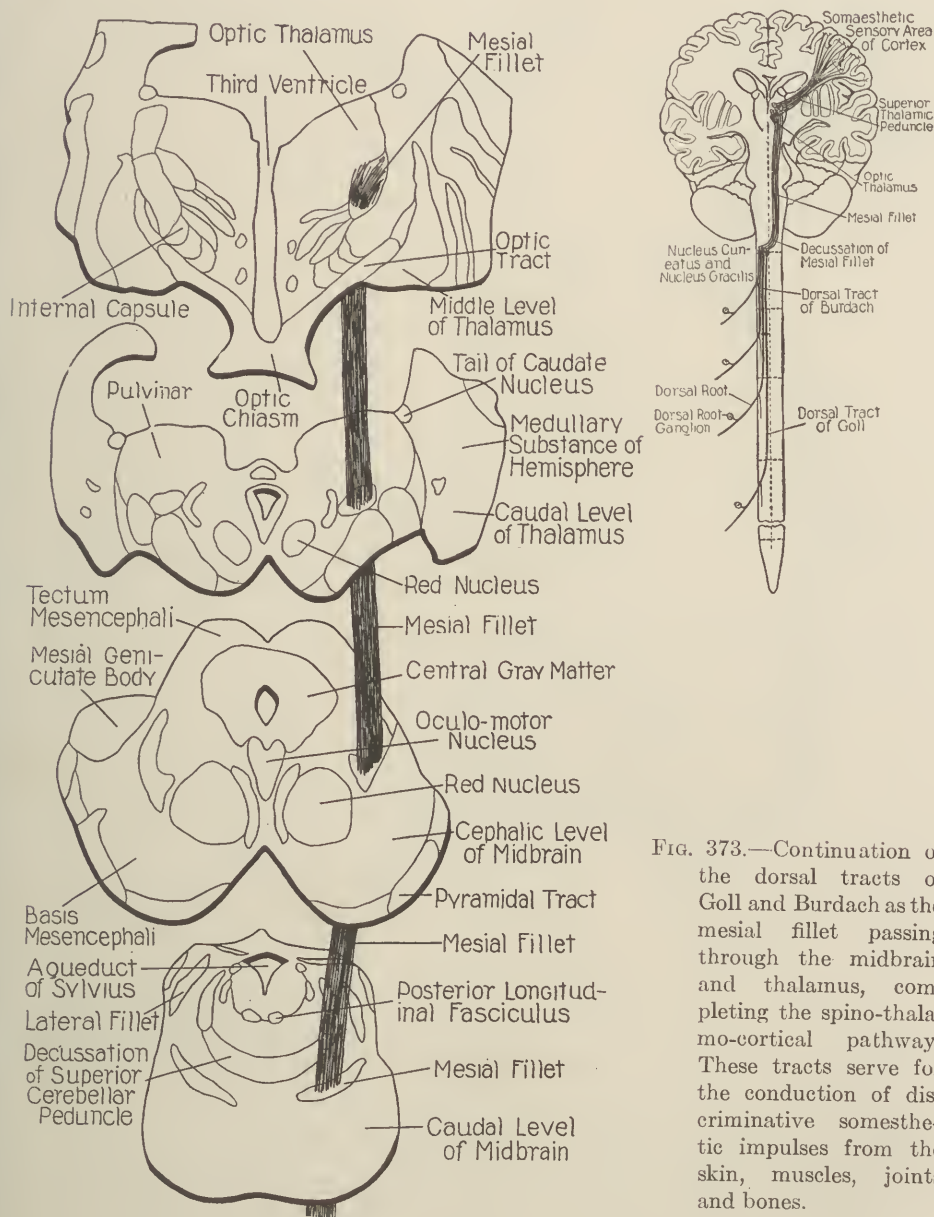


FIG. 373.—Continuation of the dorsal tracts of Goll and Burdach as the mesial fillet passing through the midbrain and thalamus, completing the spino-thalamo-cortical pathway. These tracts serve for the conduction of discriminative somesthetic impulses from the skin, muscles, joints and bones.

of a mesial group, the tractus frontal pallio-pontile, which acts in the interest of coordinating the functions of these two parts of the brain for the purposes of adequate control of the muscles; a lateral group, the tractus

parieto-temporal pallio-pontilus, which serves to bring the visual, somesthetic and auditory areas of the cerebral cortex into communication

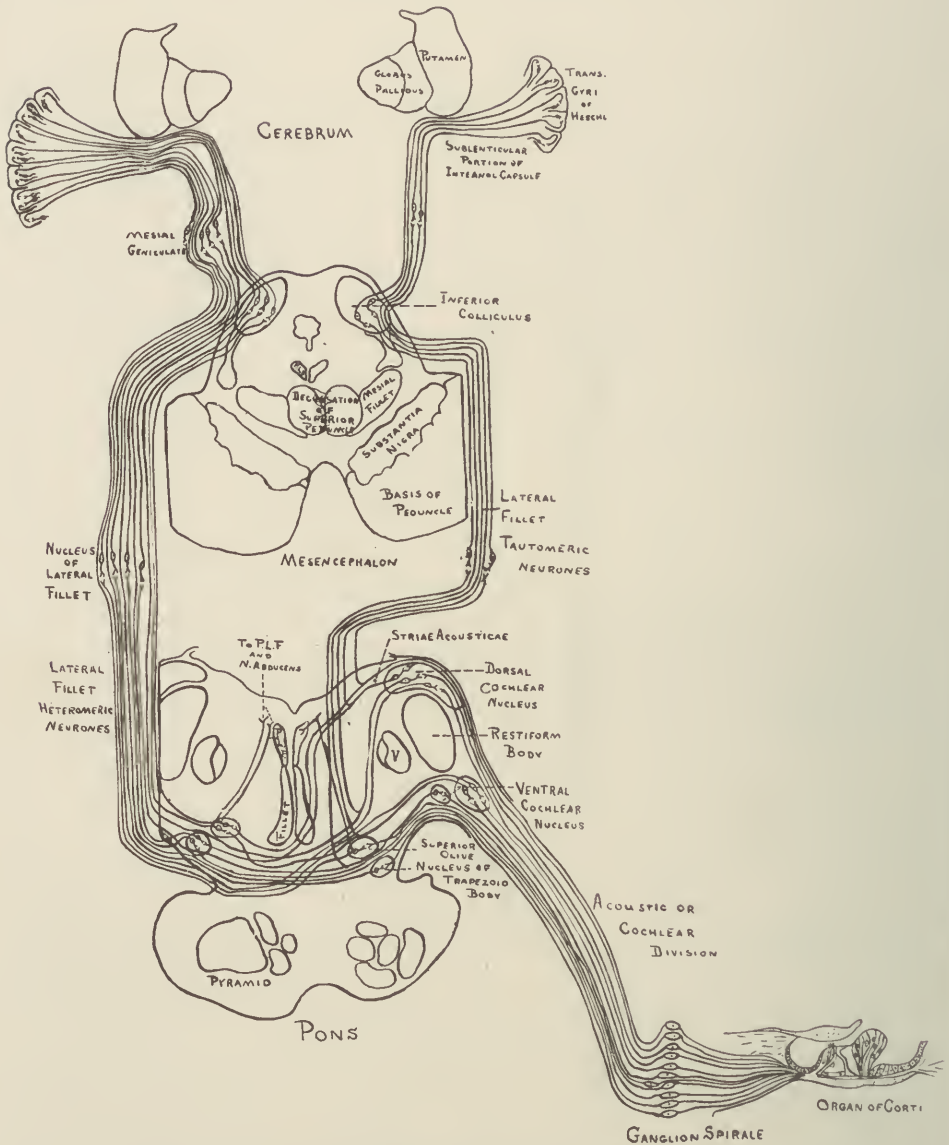


FIG. 374.—The acoustic pathway. Diagrammatic representation of the course of the acoustic or cochlear fibers of the auditory pathway, from their origin in the ganglion spirale to their cortical destination in the temporal lobe. The intermediate relay stations are shown. For the sake of simplicity the tautomeric neurones are indicated as collaterals.

with the opposite cerebellar hemisphere for the purpose of adding the proper synergic control to voluntary acts; and an intermediate group, the cortico-

spinal and cortico-nuclear tracts, which serve to connect the motor cortex of the cerebral hemisphere with the final common pathway of the spinal

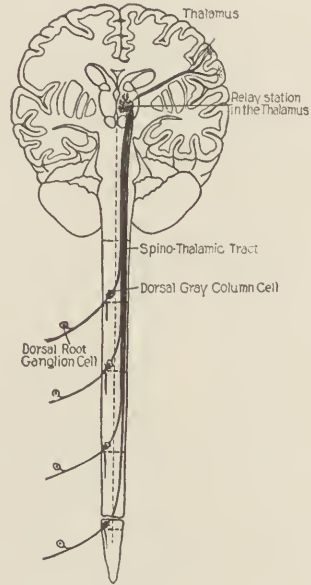
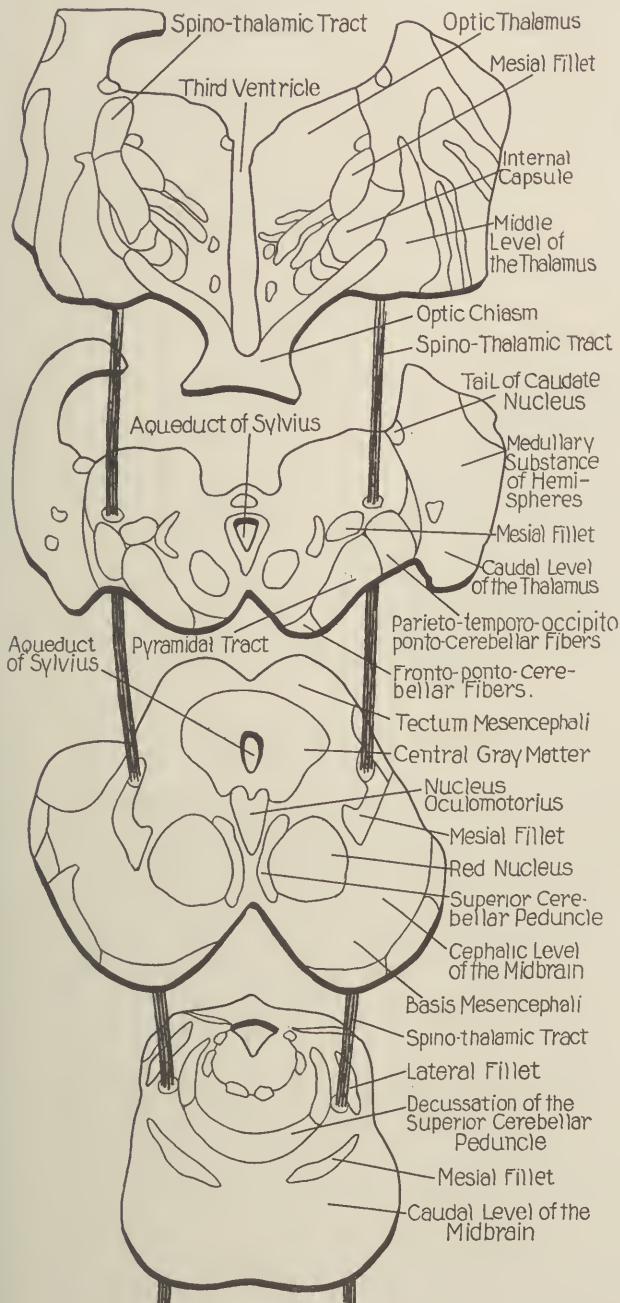


FIG. 375.—The spino-thalamic tract passing through the thalamus and midbrain and representing the thalamic and mesencephalic divisions of the spino-thalamo-cortical pathway. This tract serves to conduct impulses of affective sensibility, pain, discomfort and temperature. It is called the spinal fillet because it undergoes complete decussation in the spinal cord.

cord and brain-stem upon the opposite side. This group conveys the impulses necessary for volitional control of the muscles.

Decussations and Commissures in the Midbrain. Three important decussations take place in the mesencephalon:

1. The *decussation of the superior cerebellar peduncle*, which completes a crossed connection between the dentate nucleus of one side and the nucleus ruber of the opposite side.

2. The *ventral tegmental decussation of Forel*, which consummates a crossed connection between the red nucleus of one side and the ventral gray column cells and the cranial motor nuclei of the opposite side. This crossing, so far as the body musculature is concerned, neutralizes the first decussation in the cerebello-spinal pathway (crossing of the cerebellar peduncles) and determines the ipsilateral control which the cerebellum exerts over the muscles.

3. The *dorsal tegmental decussation of Meynert*, which establishes a complete crossing of the tecto-spinal and tecto-bulbar tracts. It makes possible a communication between the superior colliculus of the one side and the ventral horn cells and motor nuclei of the cranial nerves upon the opposite side.

The midbrain contains three important commissures which are:

1. The *inferior collicular commissure*, which connects the two inferior colliculi.

2. The *superior collicular commissure*, which serves as a commissure between the superior colliculi.

3. The caudal portion of the posterior commissure, whose significance will be considered more at length in connection with the diencephalon.

SYNDROMES OF THE MESENCEPHALON

Syndrome of the Central Gray Matter. HISTORY. A man forty-three years of age, roofer by trade, noticed that he gradually began to have double vision. After a month his upper eyelids drooped until finally he could not use either eye without lifting the upper lid with his fingers. His disability made it impossible for him to continue his trade, and although he enjoyed good health in other respects it was impossible for him to earn a living. His previous history was negative; he denied gonorrheal and luetic infection; his wife had had three children and five miscarriages. Mentally he was alert and fairly intelligent.

EXAMINATION. The examination, made at the time when he first presented himself at the clinic, showed the following:

Somatic Motor Component. The idiodynamic, reflex and tonic control of all the muscles of the body was normal. There was no loss of synergic, equilibratory or volitional control in any of the muscles of the extremities, trunk or neck. The cranial nerves showed a complete paralysis of the third nerve innervation, resulting in a double external strabismus in consequence of which both eyes were turned outward. The paralysis of both levator palpebræ muscles showed that the patient could not elevate either of his upper eyelids. The intrinsic muscles showed a complete paralysis of accom-

modation and a loss of the light reflex in both eyes. There was no involvement of the remaining cranial nerves. The patient's disturbances were confined to the paralysis of the oculomotor nerve of both sides.

The *somatic sensory component* was normal.

The *splanchnic motor and sensory components* were normal.

The mental status was normal in all respects.

The laboratory findings in the case disclosed a four plus positive Wassermann in the blood and spinal fluid.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was syphilitic.

Evidence of the focus of the lesion is furnished by the discretely limited distribution of the symptoms which were confined to muscles innervated



FIG. 376.—A. Syndrome of the oculomotor nuclei. Syndrome of the mesencephalic central gray matter. Bilateral external and internal ophthalmoplegia (paralysis of the eye-muscles) of the oculomotor type.

B. Cross section through the midbrain showing the location of the lesion in the *syndrome of the mesencephalic central gray matter*: Involvement of both oculomotor nuclei.

by the oculomotor nerves. This indicates a lesion involving the central gray matter of the midbrain immediately beneath the superior colliculus and affecting all portions of the nucleus oculomotorius on both sides.

Evidence of the circumscription of the lesion is found in the absence of all other somatic motor and sensory symptoms as well as the absence of splanchnic motor and sensory symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is syphilis of the midbrain.

NOMENCLATURE. This is known as the *central tegmental syndrome of the midbrain* or the *syndrome of the central gray matter of the midbrain*.

SUMMARY. The essential clinical features of the syndrome of the central gray matter of the midbrain are:

(a) Incomplete paralysis of the extrinsic muscles of both eyeballs, resulting in a double external strabismus.

(b) Complete bilateral ptosis, that is, drooping of both upper lids.

- (c) Bilateral paralysis of accommodation.
- (d) Bilateral loss of the light reflex.
- (e) Absence of all other motor and sensory symptoms.

Syndrome of the Interpeduncular Space. **HISTORY.** A young woman, twenty-eight years of age, a seamstress, unmarried, having always enjoyed good health, began to notice a slight drooping of both upper lids. This drooping was at first more marked on the right side than on the left; gradually it became worse until finally it was impossible for her to elevate voluntarily either upper eyelid. Simultaneously with the development of this ptosis of the lids she developed an increasing double vision which at the end of several months was so extreme that she could not look at an object with both eyes at the same time. Both eyes became displaced outward until they occupied the external canthi of the orbit. This condition is known as *double external strabismus*. She suffered for some months from a severe headache in the frontal and occipital regions and had occasional attacks of vomiting. Even the vision which she retained in either eye became considerably impaired. Four months after the appearance of her first motor symptoms she noticed that it was increasingly difficult to perform movements of the upper extremities and that she became easily fatigued in walking. The difficulties in her arms and legs were attended by an increasing stiffness, until finally both upper and lower extremities were affected by a spastic paralysis. She remained in this condition for three months before the real nature of her disorder was recognized, and then after proper treatment showed considerable improvement, although she never entirely regained the full use of her arms and legs. The ptosis disappeared in her right eye; vision in both eyes was much improved. The ptosis in the left eye persisted as did the external strabismus on that side.

EXAMINATION. Upon examination made at this time the following observations were recorded:

The *somatic motor component* showed that the reflex and tonic control of the entire body, including the trunk, neck and extremities, was markedly increased. All of the deep reflexes were extremely active; there was a bilateral ankle clonus and a double Babinski. A transitory clonus was also observed in both wrists. The superficial reflexes in the abdominal region were all absent and the abdominal muscles were rigidly contracted. The patient was bedridden and unable to move any of the four extremities. This was due to a complete volitional paralysis which, together with a marked hypertonus in the muscles, produced malpositions in the upper and lower extremities, the attitude assumed being produced by the dominance of the flexor muscles. No judgment could be given concerning the status of equilibratory and synergic control. Many abnormal associated movements were present in both upper and lower extremities.

The cranial nerves with the exception of the second and third were all normal. In the area of innervation of the third nerve, however, there was a complete bilateral ptosis, a double external strabismus, complete bilateral paralysis of accommodation and a bilateral loss of the light reflexes.

Both optic discs showed a slight elevation, the right of one diopter, the left of two diopters. Her vision was reduced in both eyes, though the greatest reduction was on the left side.

The *somatic sensory component* was normal in all sense qualities.

The *splanchnic motor and sensory components* were likewise normal.

The laboratory findings showed a four plus positive Wassermann in the blood and a negative Wassermann reaction in the spinal fluid.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was syphilitic.

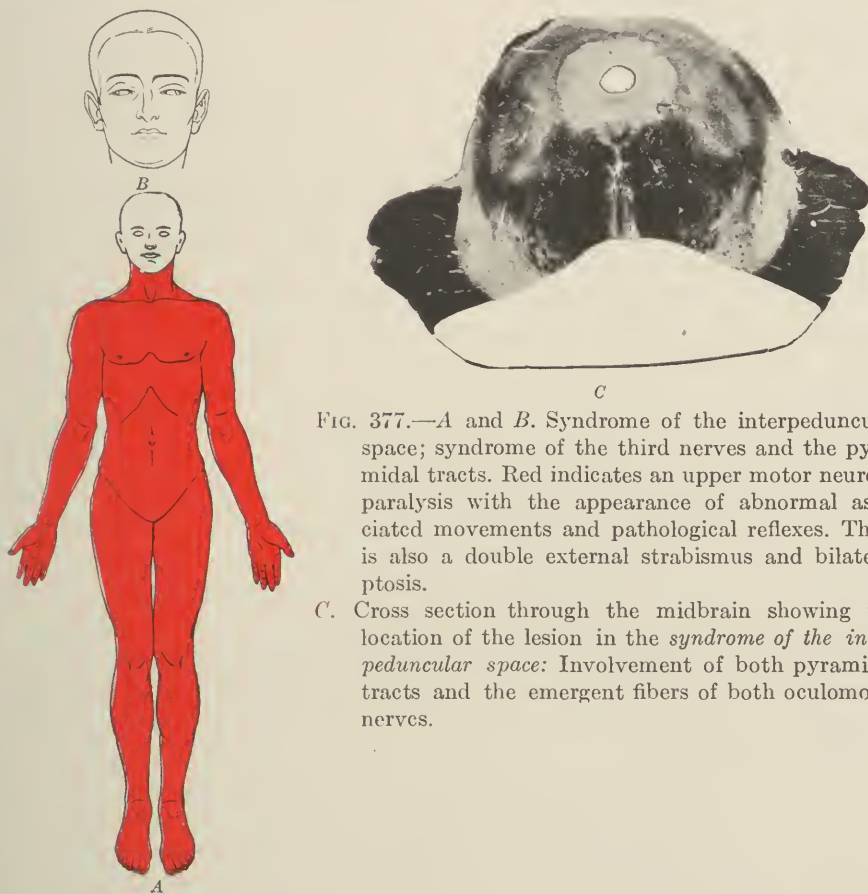


FIG. 377.—A and B. Syndrome of the interpeduncular space; syndrome of the third nerves and the pyramidal tracts. Red indicates an upper motor neurone paralysis with the appearance of abnormal associated movements and pathological reflexes. There is also a double external strabismus and bilateral ptosis.

C. Cross section through the midbrain showing the location of the lesion in the *syndrome of the interpeduncular space*: Involvement of both pyramidal tracts and the emergent fibers of both oculomotor nerves.

Evidence of the focus of the lesion is afforded by the bilateral paralysis of both oculomotor nerves combined with a bilateral involvement of both pyramidal tracts. There is an area in the midbrain where the emergent fibers of the third nerve make their escape in relation with the cerebral peduncles. Pressure in the interpeduncular space would suffice to compromise both emerging oculomotor nerves and both pyramidal tracts.

Evidence of circumscription of the lesion is afforded by the absence of all other motor and sensory symptoms, with the possible exception of the

double choked disc and failing vision, which, however, may be explained by pressure in the interpeduncular space compromising the third ventricle and thus leading to papillo-edema as a secondary effect.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is a gumma of the interpeduncular space, a syphilitic process compromising both third nerves and both pyramidal tracts.

NOMENCLATURE. This is known as the *syndrome of the interpeduncular space* or the *syndrome of the third nerves and the pyramidal tracts*.

SUMMARY. The essential clinical features in the syndrome of the interpeduncular space are:

(a) Complete paralysis of both third nerves producing double external strabismus.

(b) Complete bilateral ptosis.

(c) Complete bilateral paralysis of accommodation.

(d) Complete bilateral loss of the light reflexes.

(e) Bilateral spastic paralysis involving both arms and legs with an increase of the deep reflexes, the appearance of pathological reflexes and the disappearance of the superficial reflexes.

(f) Absence of all other sensory and motor symptoms.

Syndrome of the Cerebral Peduncle. HISTORY. The patient, a colored laborer, aged thirty-three, was admitted to the hospital complaining of inability to use the right eye. He had noticed that the upper lid of the right eye began to droop six weeks before admittance to the hospital and also that he frequently saw double. In the course of three weeks, the upper lid drooped to such a degree that it was entirely closed and at the same time the right eyeball became permanently turned outward. Four weeks after the onset of his ocular symptoms he observed that it was increasingly difficult for him to move his left arm and leg until at length he had quite lost the use of his left hand, while his gait became slow, due to the weakness and dragging of his left foot. This weakness of the left side of which he complained at first, he believed came on suddenly one morning upon his attempt to arise from bed, for on this occasion he fell and found that it was impossible for him to stand or walk.

He was married and had one child six years old. His wife had had no miscarriages. Until a year before his sickness, he drank heavily. His best weight was 201 pounds, but in the past four months during his sickness he had lost 30 pounds. For several months after the onset he suffered from night-sweats sufficient to dampen the bed clothing. He had never had gonorrhea, but eleven years before his illness he had contracted syphilis, for which he had received more or less desultory treatment. His father died at seventy years of age from consumption; his mother and three sisters were alive and well. One sister had heart disease, otherwise the family history was negative. Upon receiving proper treatment while at the hospital the paralysis of the left side cleared to a marked degree so that he was able to resume light work. The difficulty in his right eye, however, improved only slightly.

EXAMINATION. Upon examination made at the time of his admittance to the hospital, the following observations were made:

The *somatic motor component* showed that the reflex control of the right side was normal, but all the deep reflexes were markedly increased with the appearance of an ankle and wrist clonus on the left side. The superficial reflexes of the abdominal region were feeble on the left side but normal on the right. He had a left-sided Babinski and no pathological reflexes of any kind upon the right. The tone of the muscles of the left arm and left leg was markedly increased as compared with that of the right. The volitional control of the entire left side of the body showed a marked loss of strength; the right upper and lower extremities were normal. There was a marked hypertonus in the left arm and leg. There was no change in the volume, contour and consistency of the right or left upper and lower extremities. Electrical reactions were normal. Idiodynamic control over the entire body was normal. Of twenty-one tests made for automatic associated movements, fifteen groups of abnormal associated movements were observed on the left side, five of these being in the upper extremity, ten in the lower extremity. None was observed on the right side. Equilibratory and synergic control was normal on the right side of the body in so far as could be judged with the limitations imposed upon movements by the paralysis. This was true also of the left side.

The cranial nerves were all normal with the exception of the third, which showed a complete paralysis of all muscles innervated by this nerve on the right side, producing extreme right external strabismus, a complete right ptosis, loss of the light reflex on the right side, and also a complete paralysis of accommodation in the right eye. The left eye was normal in all details.

The *somatic sensory component* showed that all types of sensibility were preserved intact upon both sides of the head and face, neck and trunk, upper and lower extremities.

The *splanchnic motor and sensory components* were normal.

His mental condition was good in proportion to his actual intellectual status.

Laboratory tests showed a four plus positive Wassermann in the blood and spinal fluid.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was syphilitic, probably of the meningo-vascular type.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is a syphilitic process involving the cerebral peduncle on the right side.

NOMENCLATURE. This is known as the *syndrome of the cerebral peduncle*. It is also known as the *syndrome of alternating oculomotor hemiplegia* or the *syndrome of Weber*.

SUMMARY. The essential clinical features of the syndrome of Weber or the syndrome of alternating oculomotor hemiplegia are:

(a) Complete paralysis of the oculomotor nerve ipsilateral with the lesion producing external strabismus, complete ptosis, paralysis of accommodation and absence of the light reflex.

(b) Spastic hemiplegia contralateral to the lesion, with increased reflexes, absence of superficial reflexes, and the presence of pathological reflexes.

(c) Absence of all other sensory and motor symptoms.

Unilateral Tegmental Syndrome of the Midbrain. HISTORY. A man, forty-five years of age, salesman by occupation, unmarried, was admitted to the hospital giving as his chief complaints inability to open the left eyelid and numbness on the right side of the body. His disease had begun several months prior to his admission to the hospital, at which time he noticed an

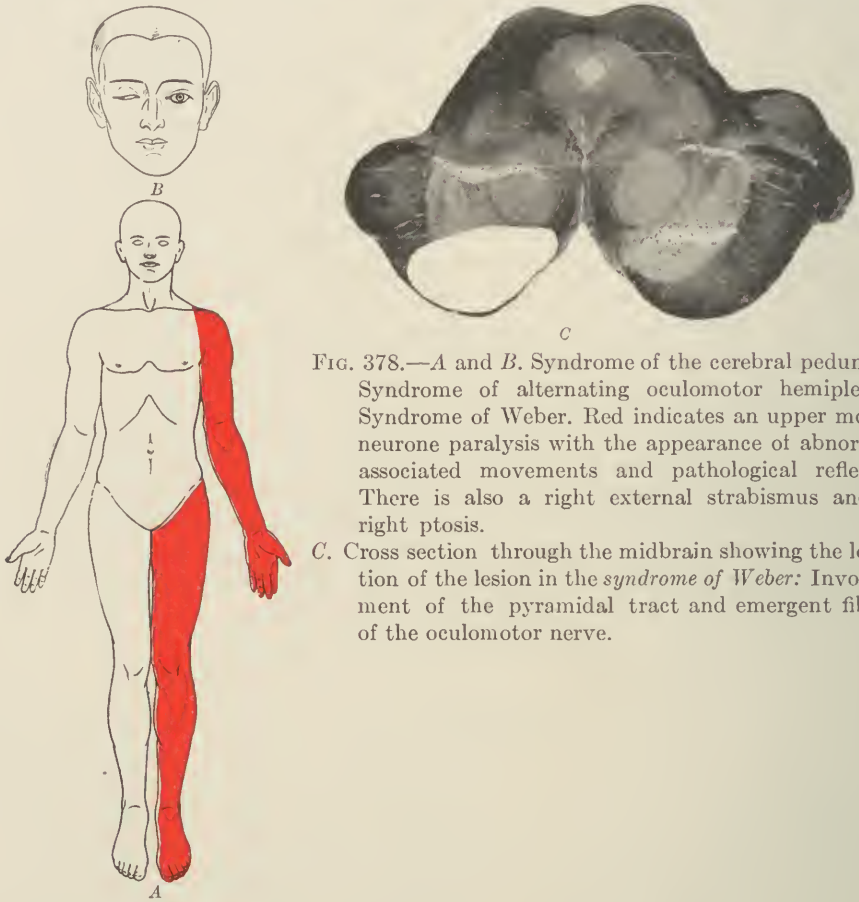


FIG. 378.—A and B. Syndrome of the cerebral peduncle. Syndrome of alternating oculomotor hemiplegia. Syndrome of Weber. Red indicates an upper motor neurone paralysis with the appearance of abnormal associated movements and pathological reflexes. There is also a right external strabismus and a right ptosis.
C. Cross section through the midbrain showing the location of the lesion in the *syndrome of Weber*: Involvement of the pyramidal tract and emergent fibers of the oculomotor nerve.

occasional diplopia. This double vision increased in severity until it was impossible for him to see without closing one eye. At this stage of his disorder the upper lid of the left eye began to droop and finally closed altogether, so that he was unable voluntarily to elevate the lid. This was not without a certain advantage to him, because it provided a means of excluding vision from the left eye and thus obviated his diplopia. He would have been better able to carry on his business under these conditions had it not been for the unnatural expression which the ptosis of the left lid gave him. Four months after the appearance of his first symptoms he experienced a peculiar

sensation in the right hand and in the right side of the tongue and face. This he noticed particularly when eating, which act he said was attended by an uncomfortable sensation inside of his mouth, principally because he did not have the right feeling with regard to his food. The numbness soon extended to the right half of the trunk and gradually involved the right leg. He experienced no pain with this disturbance, but just before coming to the hospital he noticed that there was an irregular twitching and jerky movement in his right hand and sometimes in the right side of his face. Whenever he attempted to perform any movement with his right hand, this act was accompanied by a marked tremor. The tremor was first noticeable to him while eating, and he observed that he would frequently spill water from his glass on attempting to drink. He admitted a luetic infection fifteen years before the development of his trouble. His family history showed that his father had died of paresis in an insane asylum, while his mother, who lived to the age of sixty-five, died of cancer of the stomach. He had two sisters, both alive and well.

EXAMINATION. Upon examination made at the time of his entrance into the hospital, the following observations were made:

Somatic Motor Component. With the exception of the paralysis of the left eye, the muscular system was normal in all parts of the body, in its equilibratory and synergic controls. He had lost no strength in either arm or leg, nor were any of the trunk muscles affected. He presented, however, an irregular twitching, choreic movement in the right arm and leg, most marked in the upper extremity and always increased upon voluntary attempts to perform any movement. In addition to these jerky, irregular movements on the right side of the body, he developed a coarse, irregular tremor upon attempting to move the right hand and right leg, and when much effort was exerted in these movements this tremor extended to the right side of the face. He had an incomplete left internal and external ophthalmoplegia. His automatic associated control was normal.

Somatic Sensory Component. Upon examination of sensation, it was found that he had a pronounced loss of tactile, muscle, joint and vibratory sense on the right side of the body, including the right arm, the right leg, the right side of the trunk up to the mid-dorsal and midventral line, the right side of the neck, head and face, also including the cavity of the mouth, the right half of the tongue and the right nasal cavity. In addition to the loss of discriminative sensibility there was a pronounced loss also of the pain and temperature senses. The patient did not complain of any subjective disturbance other than that already mentioned. He suffered from no pain and complained of no other form of dysesthesia.

The Splanchnic Motor and Sensory Components. These components were normal in all respects.

His mental status was normal; he was generally alert and showed no blunting of his intellectual faculties.

Laboratory tests showed a four plus positive Wassermann reaction in the blood, the Wassermann in the spinal fluid being negative.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was syphilitic, as borne out by the serological tests. Furthermore, the patient improved greatly on intensive antiluetic treatment.

Evidence of the focus of the lesion is afforded by oculomotor paralysis upon one side with a hemianesthesia of the opposite side of the body, together with the appearance of an asynergic defect and disturbances witnessed by the choreiform movements. The focus for such a lesion is found in the tegmentum of the midbrain in which the emergent fibers of

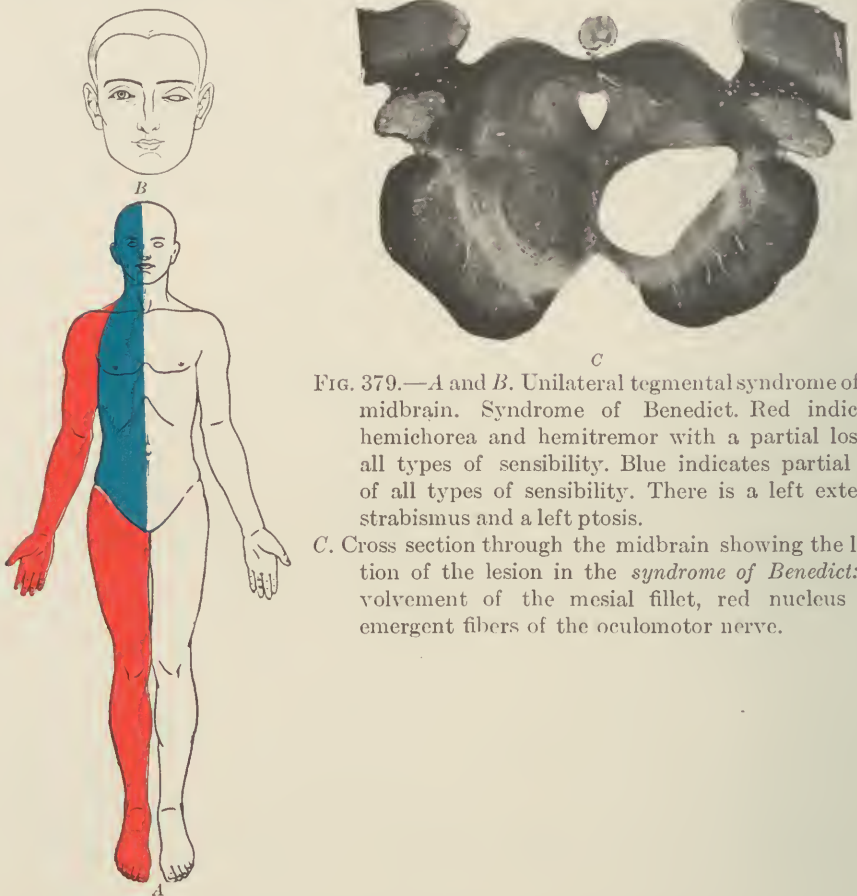


FIG. 379.—A and B. Unilateral tegmental syndrome of the midbrain. Syndrome of Benedict. Red indicates hemichorea and hemitremor with a partial loss of all types of sensibility. Blue indicates partial loss of all types of sensibility. There is a left external strabismus and a left ptosis.
C. Cross section through the midbrain showing the location of the lesion in the *syndrome of Benedict*: Involvement of the mesial fillet, red nucleus and emergent fibers of the oculomotor nerve.

the oculomotor nerve, the mesial fillet and the red nucleus might be simultaneously involved.

Evidence of circumscription of the lesion is afforded by the absence of all other sensory and motor disturbances.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is syphilis involving the tegmentum of the left side of the midbrain.

NOMENCLATURE. This is the *unilateral tegmental syndrome of the midbrain*; it is also called the *syndrome of alternating oculomotor hemianesthesia* or the *syndrome of Benedict*.

SUMMARY. The essential clinical features of the syndrome of Benedict are:

(a) Complete paralysis of the oculomotor nerve ipsilateral with the lesion, producing external strabismus, complete ptosis, a complete paralysis of accommodation and the loss of the light reflexes.

(b) Hemianesthesia involving all qualities of sensibility upon the side opposite the lesion.

(c) Hemichorea and hemitremor on the side opposite the lesion.

(d) Absence of all other *sensory* and motor symptoms.

CHAPTER XXXI

THE INTERBRAIN

THE GENERAL SIGNIFICANCE OF THE DIENCEPHALON

Intermediate Position of the Interbrain. The diencephalon is the most cephalic division of the brain-stem and the first portion of the cerebrum. It is situated between the cerebral hemispheres and immediately cephalad to the mesencephalon, for which reason it is termed the *interbrain*. It lacks several of the characteristics which distinguish the segmental portions of the neuraxis. In the first place, the basal plates play no part in its development, its entire evolution depending upon the expansion of the alar plates. In consequence of this lack of basal plate elements, the diencephalon contains no motor representation, and no emergent nerve fibers connect it with the somatic or splanchnic effectors. The interbrain differs in this respect from the spinal cord, medulla, pons and midbrain, each of which has important motor representations and is a division of the segmented portion of the neuraxis. If the strict criteria of segmentation in the central nervous system are adhered to, it is doubtful whether the interbrain should be classed as a segmented portion of the brain.

Two encephalomeres have been described in the development of the diencephalon, but these have no actual similarity to the typical encephalomeres of the lower divisions of the brain-stem.

Structurally, the diencephalon has the design of an organ for the correlation of nerve impulses. In this respect it bears a certain resemblance to the midbrain and cerebellum. As a correlating center its rôle in the evolution of the brain is of primary importance, especially in the process of telencephalization, which has resulted in the gradual shifting forward of the correlating areas to the cerebral hemispheres in the interest of more extensive and efficient associations.

Situated as it is at the actual head of the neural column in close relation to the hemispheres, it occupies a position most susceptible to the influences incident to the great expansion of the endbrain. Its own immediate environment, moreover, has been different from that of other parts of the neuraxis. It is the first of the prechordal portions of the brain. The notochord terminates at the point of transition between the midbrain and interbrain and the latter thus acquires a close relation with the mouth cavity. This relation to the mouth has been a factor of great moment in the development of the nervous system and has invested the diencephalon with functions which no other part of the brain has possessed. The close approximation of the interbrain to the roof of the skull has determined special tendencies peculiar to the diencephalon, while its position between the central axis on the one hand

and the cerebral hemispheres on the other has imposed upon it the offices of a morphological and functional intermediary.

History of the Interbrain. The history of the diencephalon shows that its evolution depended upon alterations in four distinct parts of its structure. In early stages of the neural tube the first segment of the encephalon is the forebrain (prosencephalon). This division of the brain almost immediately develops two large lateral evaginations, the optic vesicles, from which are derived the retinae of the eyes. A narrow, circumferential area of the forebrain surrounds the optic vesicle on its dorsal, cephalic and ventral aspects. This region was first recognized and described by Schulte as



FIG. 380.—Diagrammatic representation of the diencephalon (interbrain) in the vertebrate series, ventral view. Darkened area.

Petromyzon (lamprey) above. Scyllium canicula (dog-fish) below.

the *ectoptic zone*, from the three areas of which the endbrain, together with the several parts of the interbrain, take origin. As growth proceeds the ectopic zone increases in size, and from its dorsal area develop the pars epithalamica, pars thalamica, and pars metathalamica of the diencephalon. From its ventral area the infundibular region or pars hypothalamica takes origin. The cephalic area of the ectoptic zone gives rise to the endbrain. The four primitive parts of the interbrain and their derivatives are:

1. Pars hypothalamica, which gives rise to the hypothalamus.
2. Pars epithalamica, which gives rise to the epithalamus.
3. Pars thalamica, which gives rise to the thalamus proper and the subthalamus.

4. Pars metathalamica, which gives rise to the metathalamus (geniculate bodies).

An understanding of the alterations and adaptations of each of these parts is essential to a clear interpretation of the diencephalon.

Changes in and Significance of the Pars Hypothalamica. The pars hypothalamica arising from the ventral portion of the ectopic zone may be likened in its general position to the floor-plate of the neural tube. It occupies, in the adult brain, a position which has the appearance of a direct continuation of the floor-plate region, but it is probable from the embryological development of this area that it takes origin exclusively from the alar plates. Its constituent parts in the lower vertebrates, including the fish and amphibia, are:

1. The optic chiasm.
2. The lobi inferiores.
3. The infundibular region.
4. The postinfundibular eminence.
5. The lobus posterior.

Each of these parts in the lower forms has its homologue in the reptiles, birds and mammals. The process by which the changes have been wrought in passing from the lower to the higher vertebrates, as well as the probable causes underlying these alterations, is of particular interest.

In fish and amphibia this ventral portion of the diencephalon is its most conspicuous area. It comprises:

1. *The Optic Chiasm.* This is present in all vertebrates, and indicates a complete or partial crossing of the optic fibers. In consequence, the impulses received from one eye are despatched to primary end stations on the opposite side of the brain. The chiasm has its chief interest in the fact that the fibers passing through it from one side to the other end not in the diencephalon, but are transferred nearly in their entirety to the tectum of the mesencephalon, the optic lobe. A few fibers in selachians end in a primitive lateral geniculate body attached to the diencephalon. Situated above the optic chiasm and in communication with the chamber of the third ventricle is a small canal which projects outward over the optic nerve. This is the *supra-optic canal*. It represents the persistence of the original connection between the ventricle of the forebrain and the optic evagination. It has become reduced in size because of the gradual attenuation of the connecting stalk between the eye-cup and the brain. In itself, the optic chiasm is subject to but little variation and constitutes a primitive and constant feature in the pars hypothalamica. In mammals it represents an incomplete crossing of the optic fibers.

2. *Lobi Inferiores.* These lobes consist of two large evaginations, one upon either side of the median groove immediately caudal to the optic chiasm. In the fish and amphibia they are large and conspicuous elements in the ventral surface of the brain. A recess of the third ventricle projects into them. The evaginations are surrounded by gray and white matter which in some places has a distinct stratification resembling that in the tectum

mesencephali and in the cerebellum. It is evident from their connections that the lobi inferiores serve as correlating centers for general as well as special splanchnic sensory impressions, and are particularly concerned in the gustatory sense. Their gustatory connection is accomplished by way of the *superior secondary gustatory* nucleus of the mesencephalon, situated in the central gray matter. The course of the fibers to this nucleus is either in or mesial to the direct cerebellar tract. The lobes are connected by means of two pathways with still higher correlating centers. One of these pathways, the *tractus lobo-epistriaticus*, connects the inferior lobes with the epistriatum, a portion of the forebrain which serves the purposes of higher sensory elaborations, and influences the corpus striatum in the interest of despatching impulses to produce motor reactions. The second tract is the *tractus lobo-thalamicus* which connects the inferior lobes with the thalamus proper and serves to produce certain reactions in response to gustatory stimuli. These reactions are undoubtedly essential to selecting and procuring food. It is also probable that the general splanchnic sensory pathway has its ending in the inferior lobes. In these lobes are received all of the sensory impulses coming in from the gastro-intestinal tract. It is also likely that impulses from the genito-urinary tract are here correlated in the interest of those sexual activities necessary to the propagation of the species. The lobi inferiores, therefore, serve as important correlating centers for gustatory and general splanchnic impressions. The correlations occurring in this part of the brain participate in fundamental processes for maintaining life and perpetuating the species.

The inferior lobes have undergone great reduction in passing from the fish to those forms living upon the land. A marked reduction in their size is seen even in the amphibia. This change is undoubtedly indicative of a decrease in the importance of the gustatory sense which, in the bony fish particularly, is a highly important element in the sensorium. The inferior lobes are for this reason more developed in teleosts and ganoids than in the selachians, which depend much more upon the olfactory than the gustatory sense.



FIG. 381.—Diagrammatic representation of the dienkephalon (interbrain) in the vertebrate series, ventral view. Darkened area.

Salmo salar (salmon) above. *Rana esculenta* (frog) below.

In birds and mammals it is impossible to identify any structures upon the ventral surface of the brain of such prominence as the inferior lobes. On the other hand, in birds as well as in mammals, there is a marked eminence caudal to the optic chiasm, known as the *postchiasmatic eminence*. This eminence consists of a median groove, upon either side of which the floor of the brain shows two small protuberances, the *eminentiæ laterales*. The lateral eminences are regarded as the much reduced vestiges of the inferior lobes and the groove between them corresponds to the postchiasmatic groove in the fish. The postchiasmatic eminence has been called by some anatomists the *bulbus infundibuli*. It constitutes one of the elements entering into the formation of the mammalian *tuber cinereum*. In mammals it still



FIG. 382.—Diagrammatic representation of the diencephalon (interbrain) in the vertebrate series, ventral view. Darkened area.

Alligator mississippiensis (alligator) above. Columba (pigeon) below.

contains gray and white matter, but in no place shows a tendency to the characteristic stratification of the inferior lobes in fish. The reduction of these structures to their vestiges in birds and mammals is dependent upon the regression in importance of the gustatory sense, the reasons for which are evident. Air-breathing animals undoubtedly depend much more upon the olfactory sense for detection and selection of food than upon the gustatory sense. Thus the transition from the large lobi inferiores of the fish to the reduced infundibular bulb with its two lateral eminences in birds and mammals is explained by the diminution in the activity of the gustatory sense and the replacement of functions by a much augmented olfactory sense.

3. *Infundibular Region.* This region of the vertebrate brain has greatest interest in its connection with the mouth cavity. It seems to have had an especially important function in ancestral vertebrates. The infundibular region in certain larval vertebrates, as ammocetes, and also in the larval and adult forms of ascidians, is connected with the mouth cavity by means of a small tubular aqueduct lined with ciliary epithelium. This aqueduct is the *bucco-neural duct*, which provides a true water vascular system for the central nervous organs. It permits water from the mouth to pass into the central canal of the brain and spinal cord. In animals in which this duct is present, there is a collection of ganglionic cells situated at the upper end of the canal. This ganglion seems to act in a manner similar to that of the *osphradial organ* (scent organ) of mollusca. It therefore is related to the olfactory apparatus and probably serves to test the quality of water admitted from the mouth into the nervous system. The infundibular region in this sense was functionally active in the ancestral vertebrates, and although the bucco-neural duct has been obliterated, a *subneural ganglion* situated at its upper extremity still persists in the neural portion of the hypophysis cerebri. Some authorities believe that the hypophysis itself arose as an organ related to the sense of taste and that the infundibular region was the portion of the brain



FIG. 383.—Diagrammatic representation of the diencephalon (interbrain) in the vertebrate series, ventral view. Darkened area.

Lepus cuniculus (rabbit) above. *Canis familiaris* (dog) below.

which received afferent nerve fibers of gustatory sense in the same manner that the olfactory bulb receives the afferent fibers for the sense of smell. The necessity of this ancient connection providing a water vascular system for the nervous system has been obviated by the complete vascularization of the nerve tissues. The former connection between mouth and brain has ceased to exist. There is still evidence, however, of this primitive communication. The pituitary gland in its early formation is an evagination from the roof of the mouth which comes into contact with a similar evagination from the infundibular region. The infundibular evagination becomes the *infundibular process*. The pituitary mouth pouch fuses with the infundibular process and forms the hypophysis cerebri. For a considerable

period during development, after this fusion has occurred, a tubular stalk extends from the roof of the mouth to the floor of the brain. This primordial tube eventually disappears.

The relation between the evagination from the roof of the mouth and the floor of the interbrain is a constant feature in the development of the vertebrate brain. It unquestionably represents an inherent mutual attraction between these two parts, the original impetus of which was the formation of a water vascular system. The primitive design has been altered; but here as elsewhere the process of adaptation makes full use of the old in evolving the new. The evolution of the infundibular region manifests certain changes which in substance seem to indicate that the evagination from the roof of the mouth was at first strongly attracted to the floor of the brain. Primitively the floor of the diencephalon showed but little modification to the approach of the pituitary pouch. In all probability this area of the brain was so much engaged in essential functions of its own that it felt but slightly the influence of adjacent structures. Subsequently, as these functions became less essential, the floor of the infundibular region became more susceptible to the proximity of the evagination from the mouth. The apparent recession in the functional importance of the diencephalic floor is clearly demonstrated in the phyletic modification of the hypophysis cerebri.

In *selachians*, the infundibular region consists of a caudal prolongation of the floor of the brain situated behind the inferior lobes. It presents a ventral or pituitary and a dorsal or saccular surface. The pituitary surface is thick and smooth. It acquires connection with the pituitary pouch and constitutes the neural element in the hypophysis. The saccular surface is thin and greatly convoluted. Its convolutions come into intimate relation with the pia mater to form more or less distinct glomeruli. These glomeruli secrete a substance which is deposited in the third ventricle in a manner similar to that of other chorioidal glands. The convoluted vascular structure is the *saccus vasculosus*.

In *amphibia*, the same conditions are present except that the saccular surface, which in the fish forms such a densely convoluted and vascular structure, is much simpler in its appearance. A few undulations replace the numerous convolutions of the *saccus vasculosus*. The pituitary surface is in all respects similar to that in the fish and is in contact with the pituitary gland.

In *birds*, the two surfaces of the infundibular region are still present. The pituitary surface is smooth and thick. It is in contact with the pituitary gland. The saccular surface is likewise thick but presents a number of convolutions which are fairly vascular. It encloses, as in the case of fish and amphibia, a recess of the third ventricle. One striking difference, however, between the bird and the lower vertebrate has made its appearance. In birds a distinct stalk connects the extremity of the infundibular region with the floor of the interbrain. Here the mutual attraction between the floor of the brain and the pituitary pouch results in an actual evagination from the infundibular region. This development now distinguishes an *infundibular process* attached by means of the stalk to the floor of the brain.

In *mammals*, essentially the same arrangements appear as in the bird. The infundibular region has become differentiated into a postchiasmatic eminence, an infundibular stalk and an infundibular process. In all forms except the felidæ (the cat family) the infundibular process is solid and contains no recess of the third ventricle. The felidæ, therefore, form an intermediate stage between the lower vertebrates and other mammals.

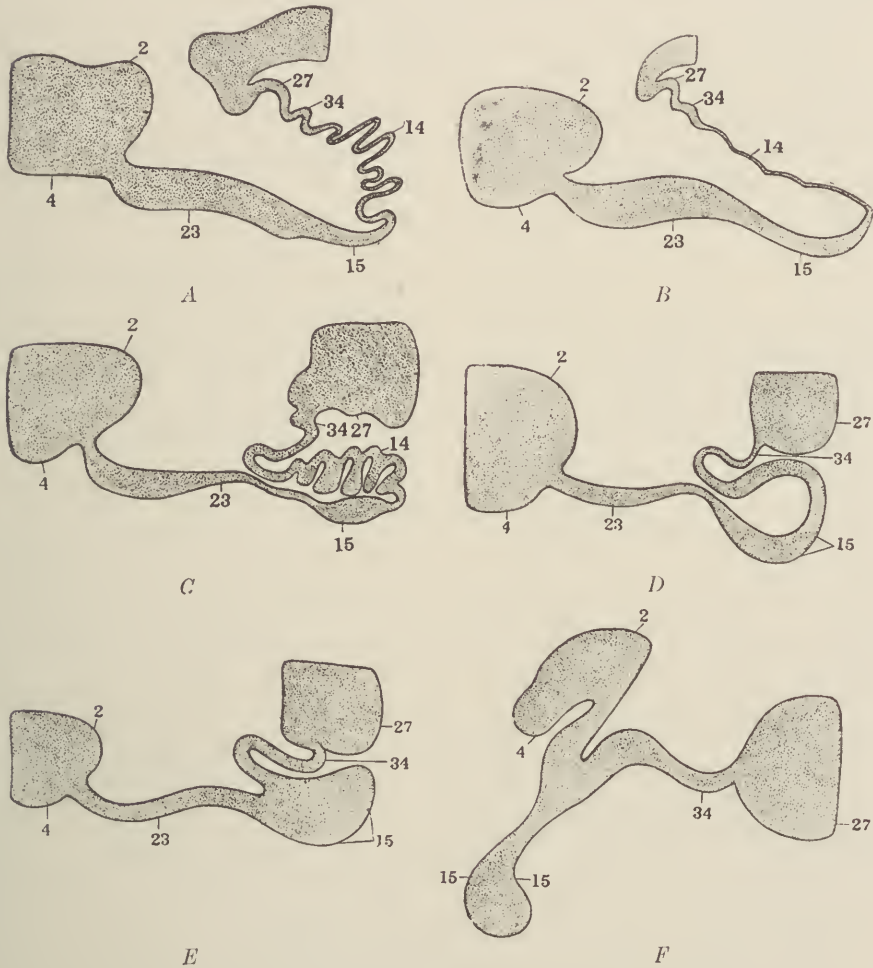


FIG. 384.—Infundibular region in the comparative series.

A—Dog-fish; B—frog; C—fowl; D—cat; E—dog; F—man; 2, chiasmatic process; 4, chiasm; 14, infundibular process, saccular surface; 15, infundibular process, pituitary surface; 23, median post chiasmatic groove; 27, mammillary body (posterior lobe); 34, post infundibular eminence.

The reason for this intermediate position of the felidæ in regard to the hypophysis cerebri is not clear at present. The entire infundibular process in the mammal is surrounded by the tissue of the pituitary gland. The infundibular process in all mammals, except the primates, is connected by a short broad stalk to the floor of the interbrain with which it is in close relation. In man and the anthropoid apes the relations of the infundibular

process have undergone a marked change, which has resulted in the development of a long, slender infundibular stalk, the separation of the hypophysis cerebri by a considerable distance from the floor of the brain, together with a rotation forward of the infundibular process through 45 degrees. These alterations in the primates appear to be significant of a regressive process in the functional activities of the part of the infundibular region which has been drawn out into the infundibular process and stalk.

The gradual recession of the saccus vasculosus depends upon the fact that other and more ample collections of chorioidal glands develop in different parts of the brain.

The significance of the infundibular process and the stalk in man is not clear at the present time. This part of the hypophysis cerebri may represent a structure active in the metabolism of the body. That it plays any part in the nervous mechanism seems doubtful, since it has no direct fiber connection either with the periphery or with the central axis.

4. *The Postinfundibular Eminence.* This is a small elevation observed immediately caudal to the base of the infundibular stalk. It has been interpreted as the vestige of the saccus vasculosus in fish, but this view cannot be accepted. In many forms it contains a commissure known as the *postinfundibular commissure* which undoubtedly is related to the gustatory sense.

5. *The Lobus Posterior.* Immediately caudal to the postinfundibular eminence there is a large protuberance in the floor of the diencephalon. In fish and amphibia it extends transversely across the floor. This protuberance contains a cavity which communicates with the third ventricle and is known as the *lobus posterior*. In the lower forms it receives fibers which make their way into the diencephalon from the olfactory lobe. In birds and mammals it ceases to contain a cavity and is excluded from all communication with the ventricle. It becomes a solid body divided in the midsagittal line by a sulcus giving rise to the *corpora mammillaria*. These structures serve as relay stations in the olfactory pathway.

It is clear from these facts that the pars hypothalamica of the inter-brain was primitively concerned with the correlation of gustatory, general splanchnic and olfactory impulses which served the purposes of selecting and procuring food. That this region of the brain has, in the course of evolution, undergone marked reduction is due to the fact that other areas have superseded it in the functions which it originally controlled. Furthermore, the gustatory sense has become much reduced in its importance as a type of sensibility in the higher animals.

Changes in and Significance of the Pars Epithalamica. This portion of the diencephalon is represented by its roof-plate, the structure of which constitute the *epithalamus*. The prosencephalic roof-plate has certain characteristics which are constant in all forms, particularly the presence of three arches which, beginning at the cephalic extremity of the roof, are the *paraphyseal arch*, the *postvelar arch* or *dorsal sac* and the *epiphyseal arch*. The paraphyseal arch gives rise to an evagination which forms the paraphysis.

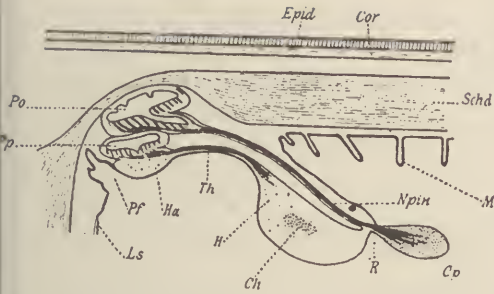


FIG. 385.—Schematization of pineal region in cyclostomes. (Studnicka, 1905.)

Ls—lamina terminalis; Pf—paraphysis; Pp—parapineal organ; Po—pineal organ; Ha—habenular ganglion; Th—tractus pinealis; Ch—commissura habenularis; R—recessus pinealis; Cp—commissura posterior; Npin—nervus pinealis.

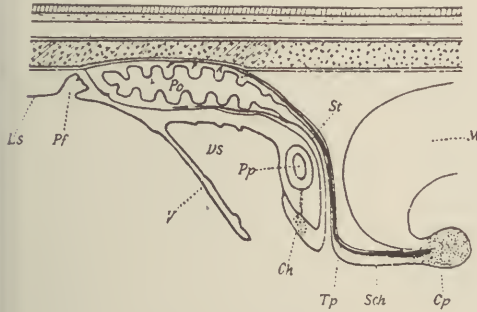


FIG. 387.—Schematization of pineal region in teleosts. (Studnicka, 1905.)

Ls—lamina terminalis; Pf—paraphysis; Ds—dorsal sac; V—velum transversum; Ch—commissura habenularis; Po—pineal organ; St—stalk of pineal organ; Tp—tractus pinealis; Sch—pars intercalaris anterior; Cp—commissura posterior; M—midbrain.

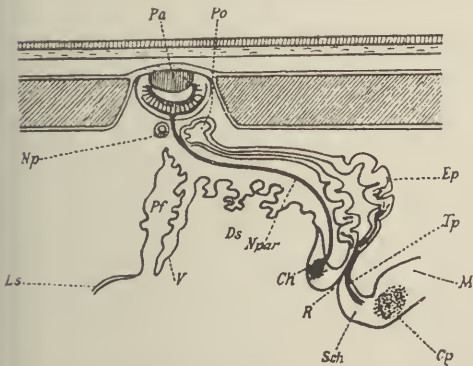


FIG. 389.—Schematization of the pineal region in sphenodon. (Studnicka, 1905.)

Ls—lamina terminalis; V—velum transversum; Pf—paraphysis; D—dorsal sac; Ch—commissura habenularis; Pa—parapineal organ; Npar—nervus parapinealis; Po—pineal organ; Ep—proximal portion pineal organ; Tp—tractus pinealis; Sch—pars intercalaris posterior; Cp—commissura posterior; M—midbrain; Np—accessory parapineal organ; R—Recessus pinealis.

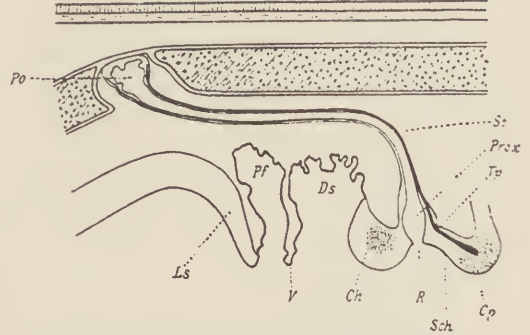


FIG. 386.—Schematization of pineal region in selachians. (Studnicka, 1905.)

Ls—lamina terminalis; P—paraphysis; V—velum transversum; Ds—dorsal sac; Po—pineal organ; St—stalk of pineal organ; Ch—commissura habenularis; R—recessus pinealis; Cp—commissura posterior; Sch—pars intercalaris posterior; Prox—proximal portion; Tp—tractus pinealis.

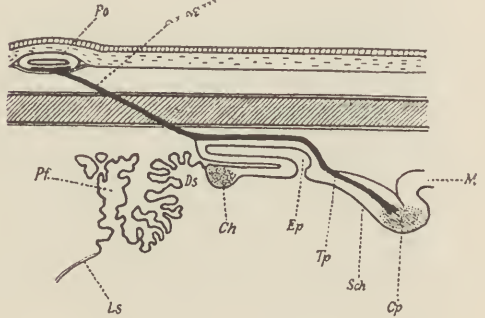


FIG. 388.—Schematization of the pineal region in amphibia. (Studnicka, 1905.)

Ls—lamina terminalis; Pf—paraphysis; Ds—dorsal sac; Ch—commissura habenularis; Po—pineal organ; Npin—nervus pinealis; Ep—proximal portion pineal organ; Tp—tractus pinealis; Sch—pars intercalaris posterior; Cp—commissura posterior; M—midbrain.

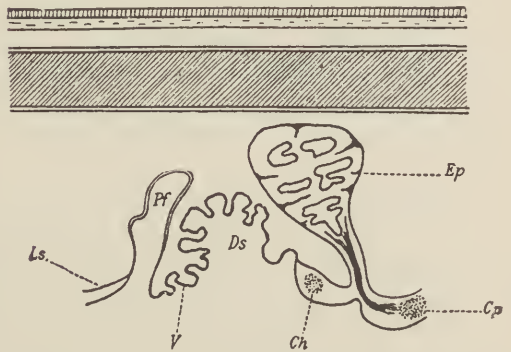


FIG. 390.—Schematization of the pineal region in ophidia. (Studnicka, 1905.)

Ls—lamina terminalis; P—paraphysis; V—velum transversum; Ds—dorsal sac; Ch—commissura habenularis; Ep—proximal portion of pineal organ (epiphysis); Cp—posterior commissure.

This organ is glandular in structure and in certain forms is equipped with a sinusoidal circulation in many respects similar to that of the liver. In the lowest vertebrates, the cyclostomes and selachians, the paraphysis does not attain very marked dimensions. It is present as an evagination from the roof-plate and contains five or six reduplications. In amphibia, however, it becomes a conspicuous organ, in both the size and complexity of its development. It extends from the anterior extremity of the roof-plate to the cerebellum, arching over the midbrain. This large glandular structure undoubtedly contributes secretion, in part at least, to the cerebrospinal fluid. Its presence may explain the much reduced size of the saccus vasculosus in amphibia. The remainder of the paraphyseal arch gives rise to the *lateral tela chorioidea* or the chorioid glands which extend into the ventricles of the cerebral hemispheres. The postvelar arch or dorsal sac is constant in all vertebrates and becomes highly developed in mammals in forming the

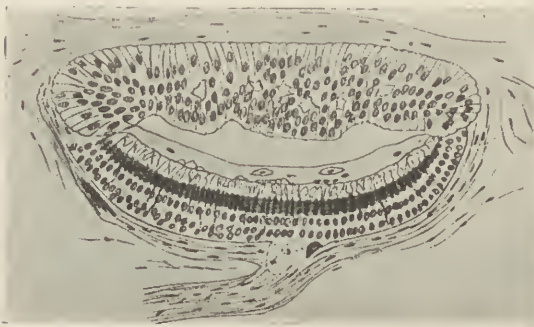


FIG. 391.—The pineal eye in *iguana tuberculata*.
(Klinckowstroem, 1894.)

superior tela chorioidea or chorioid glands of the third ventricle. The epiphyseal arch presents a much more complicated history. It may give rise either to a gland of internal secretion, the *pineal gland*, or a pair of *parietal eye-like structures* which come into relation with the roof of the skull.

In the cyclostomes the epiphyseal arch develops two eye-like structures, one connected with the *posterior commissure* and the other with the *superior or habenular commissure*.

In selachians and other fish, the tendency to the formation of eye-like structures has entirely disappeared. The specialization of the epiphyseal arch is in the direction of glandular formation. In amphibia, however, there is a distinct resumption of the differentiation of a parietal eye situated in the middle of the head. This eye in amphibia has a retina and a structure corresponding in many respects to a cornea. Nerve fibers connect it with the posterior commissure.

In the primitive reptiles, particularly in lizards, the differentiation of the epiphyseal arch reaches its highest degree in the formation of the eye-like structure. This eye has a well defined cornea, lens and retina, together with a nerve connecting it with the superior commissure. Another portion of the epiphyseal arch, however, develops marked glandular characters, so that in the primitive forms of reptiles the differentiation of the glandular structures is pronounced. In more recent reptiles, especially the snakes, the tendency toward the differentiation of the eye-like structure has disappeared and the epiphyseal arch gives rise to a glandular organ situated above the

roof of the diencephalon. This is also the case in birds where the tendency to gland formation is even more marked. The gland itself communicates by means of its follicles with the third ventricle or in part contributes its secretion to the blood.

In mammals, the organ has characters which justify the opinion that it is a glandular structure. Here, however, it has no duct, but depends upon the blood vessels for the collection of its secretion. In other words, it is a gland of internal secretion and part of the endocrine system.

In those instances in which an eye-like structure is formed, the animals possessing such an organ are in need of information received by a distance receptor placed in the parietal region of the head. Such a need is clearly understood in the case of sluggish animals, such as the lizard, whose head movements are limited and whose range of vision would serve to include but a limited portion of their horizon. The addition of a third eye would be a great advantage. The theory, however, that the pineal gland in the mammal is the vestige of the parietal eye cannot be accepted. The histology of the epiphysis gives evidence that in all vertebrates this portion of the brain possesses a pluripotential activity whose fundamental tendency is in the interest of glandular differentiation. In a few instances, as in cyclostomes, amphibia and the primitive reptiles, the epiphyseal arch has become further differentiated in the interest of a highly specialized sensory mechanism which has or has had visual function. As a gland it may in some cases contribute its secretion to the cerebrospinal fluid; but in the higher vertebrates, as in ophidians, chelonians, birds and mammals, it is an endocrinic organ contributing the products of its secretion to the blood stream. There can be no direct relation between the parietal eye and the pineal gland, but each is of itself an adaptive modification answering the demands for or representing an inherent impulse toward the development of the parietal eye on the one hand or a glandular organ on the other. This development is in response to the special needs of the animal. The pineal body as it appears in mammals may not be regarded as the vestigial or metamorphosed, degenerated or atrophic remnant of the parietal eye in lower vertebrates.

Changes in and Significance of the Pars Thalamica and Pars Metathalamica. The pars thalamica in the lower vertebrates is an inconsiderable portion of the diencephalon. In mammals it has become the most conspicuous element of the interbrain. This change is dependent upon certain additions which have taken place in the course of evolution. This part of the diencephalon consists of two subdivisions, the *thalamus* proper and the *subthalamus*. The greatest increase in size has occurred in

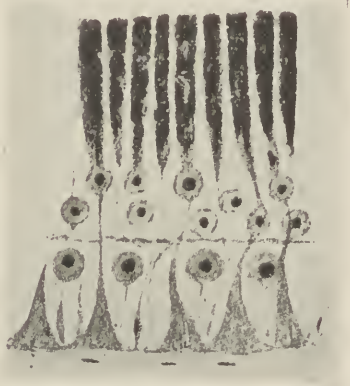


FIG. 392.—The structure of the retina in the pineal eye in *sphenodon punctatum*. (Spencer, 1886.)

the thalamus, whose more ancient portions have retained their original significance and position.

THE PALEOTHALAMUS (*old thalamus*). The primitive pars thalamica is known as the *paleothalamus* and consists of a number of nuclei in the gray matter about the third ventricle. These nuclei constitute a mesial group of cell collections which comprise the *nucleus anterior*, the *nucleus medius*, the *medial center* and the *ganglion habenulæ*. All of these nuclei are differentiated for the purpose of primitive thalamic correlations such as those which occur in the fish and lower vertebrates. Clinical evidence seems to indicate that some of these primitive functions of the old thalamus are retained in man

and that many of the most effective activities of the brain depend upon these thalamic centers. It is probable that this part of the central nervous system in the lower vertebrates is an organ designed for an extremely high degree of sensory correlation. It assembles not only those impulses necessary to somesthetic, auditory and visual sensibility, but is also concerned in olfactory and gustatory as well as general visceral sensibility. The proper coordination of the impressions received by these sensory avenues results in the development of a generalized sensory status, the *general sense of well-being*. The establishment of such a sense of well-being and the variations in it are the primitive sources out of which arise the incentives of behavioral reactions. The maintenance of this sense depends upon adequate contributions



FIG. 393.—Reconstruction showing development of the pineal region in a 23 mm. embryo of man. (John Warren, 1917.)

LT—Lamina terminalis. P—Paraphysis. V—Velum. P, V, A—Postvelar arch. E—Epiphysis. P, C—Posterior commissure.

from all types of sensibility in the body. Disturbances in this sense may be occasioned by inadequate, excessive or improper stimulation received through any of the avenues of special or somesthetic sensibility. Excessive stimulation of the surface of the skin disturbs the sense of well-being and leads to the production of such motor activities as would provide escape from the irritation, as well as avoidance of it. Excessive, irritating stimuli due to light, too rapid motion, unaccustomed objects, also produce discomfort and result in movements of escape or avoidance. Splanchnic sensory impulses received from the gastro-intestinal tract as a result of more or less complete emptiness of the alimentary canal, disturb

the sense of well-being and eventually determine a series of sensory and motor activities necessary for procuring and selecting food. All of these movements have a close generic relation. They are intimately connected with acts which serve to maintain the primitive state of well-being. In character they are necessarily more complex than the simple and associated reflexes because they determine a series of motor performances to accomplish a definite and relatively complex purpose. The animal which depended solely upon its simple and associated reflexes for protection would have but a slight margin of safety, and although these more simple combinations of movements might furnish immediate escape from inimical factors, they



FIG. 394.—Reconstruction showing the development of the pincal region of a sheep embryo of 48.4 mm. (*John Warren, 1917.*)

FM—Foramen of Monro. P—Paraphysis. V—Velum. SC—Commissura habenularis. E—Epiphysis. PC—Posterior commissure. OC—Optic chiasm.

would be ineffectual in providing consistent protection. Purposiveness in protective acts saves the animal from starvation and also from destruction by the hostile elements in its environment. Such protective actions which grow out of the necessity of maintaining the sense of well-being have in them a definite instinctive quality. They are transmitted directly to the individual from the ancestors; they are an ancestral endowment, an inherited capital with which to start life and to keep it going. For this reason they are phylogenetically conditioned and form the basis of the instinctive reactions. The sense of well-being is the governor which calls these instinctive reactions into play, while the changes to which this sense is subject serve, in many instances, as the final incentives to action.

Hunger is a decided change in the sense of well-being. It depends upon a combination of splanchnic and somatic sensory impressions which call out the instinctive reactions necessary to procure food. Without this change in the sense of well-being and an adequate response thereto, the animal would starve.

A change in feeling-tone may so disturb the well-being sense as to result in the effort to escape that which causes or threatens discomfort. Such a change may depend upon a combination of visual, auditory, olfactory, often splanchnic and somatic sensory impressions. This combination is a primitive representation of the emotion of fear, whose motor response is the instinctive reaction of flight. The change in feeling-tone which results in the primitive emotion of anger may so disturb the sense of well-being as to provoke instinctive reaction of attack. This emotion also results from a combination of sensory impressions.

The changes in feeling-tone which underlie sexual excitement (sexual emotion) are primitively dependent upon sensory impressions which take origin in the splanchnic and somatic systems. Although it is not wholly

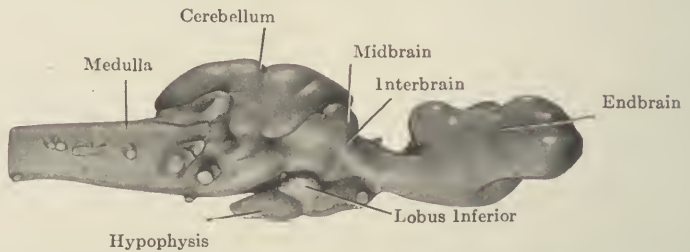


FIG. 395.—Brain of dog fish (*Scyllium canicula*) illustrating the earliest phases in the process of telencephalization.

clear at present along what exact lines the afferent impulses which stimulate sexual activity make their way to the central nervous system, there can be no doubt that the response to sexual emotion is primarily dependent upon a mechanism similar to that of the other instinctive reactions.

Changes in the feeling-tone resulting from a combination of visual, auditory and somesthetic impressions may so disturb the sense of well-being as to determine the energetic, protracted and complex instinct reactions of protection growing out of the emotion of parental possession. In all instances it is only when specific instinctive reactions have satisfied any of the changes in feeling-tone giving rise to these emotions, that the balance in the sense of well-being reestablishes itself.

These primitive emotions and many others of the same kind are based primarily upon appropriate combinations and associations of sensory impressions. They produce the changes in the general feeling-tone that result in the instinctive reactions, without which life in its more highly organized forms would be impossible. The correlations of these many different sensory impressions would of necessity require a specialized portion of the brain. The paleothalamus seems to be best calculated to serve as the general

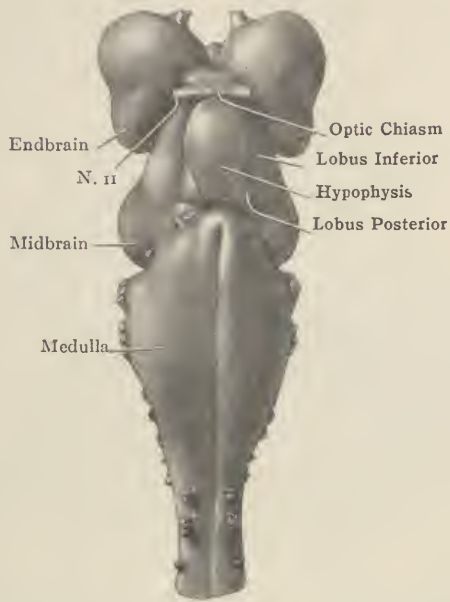


FIG. 396.—*Cyclostomes*: Structures in the floor of the third ventricle of the lamprey (*Petromyzon*) indicated in heavy type.

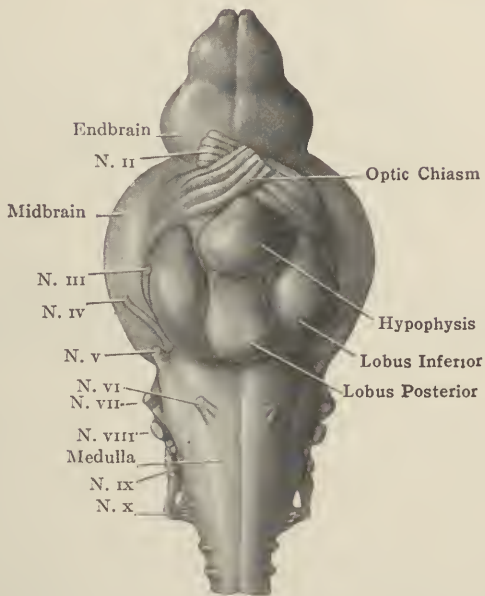


FIG. 397.—*Teleosts*: Structures in the floor of the ventricle of the salmon (*Salmo salar*) indicated in heavy type.

receptacle for all types of sensibility. It has ancient connections with the end organs of vision, hearing, smell, taste, and also with the receptors of body and visceral sensibility. Having a common assembling ground in the thalamus, the sensory impulses from the entire body may participate in the regulation of the primitive feeling tone. The combinations of sensory impressions producing specific phases of feeling tone may rightly be regarded as the essence of the primitive emotions. Their persistence in the higher forms of animals is not difficult to discern. They have been attributed



FIG. 398.—Brain of salmon (*Salmo salar*) illustrating the early phases in the process of telencephalization.

to the paleothalamus, as this part of the brain seems to be invested with a functional responsibility related to the development of the emotions and emotive expressions.

THE NEOTHALAMUS (*new thalamus*). This presents a marked expansion in the lateral portion of the interbrain which is most pronounced in the mammal. It undoubtedly indicates an important stage in telencephalization, during which the sensory pathways have shifted their allegiance from more primitive parts of the brain to the expansive cerebral hemispheres.



FIG. 399.—Brain of alligator (*Alligator mississippiensis*), illustrating the intermediate phases in the process of telencephalization. Due to the development of the end-brain, the interbrain has partially disappeared from surface view.

The lateral nuclei in the neothalamus, including the *nucleus lateralis*, the *nucleus ventralis* and the *nucleus dorsolateralis*, act as relay stations for the fibers of the spinal, bulbar and trigeminal fillets, in order to transmit the impulses conducted by these tracts to their final sensory areas in the cerebral cortex. The *pulvinar* and *lateral geniculate body* serve as nuclei of relay for fibers of the optic tract (optic fillet) and transmit visual impulses to the occipital cortex.

The Subthalamus. Ventral to the thalamus is the *subthalamus*, probably as ancient a part of the brain as the paleothalamus. It acts as a center for motor coordination. It receives fibers from the dorsal part of the

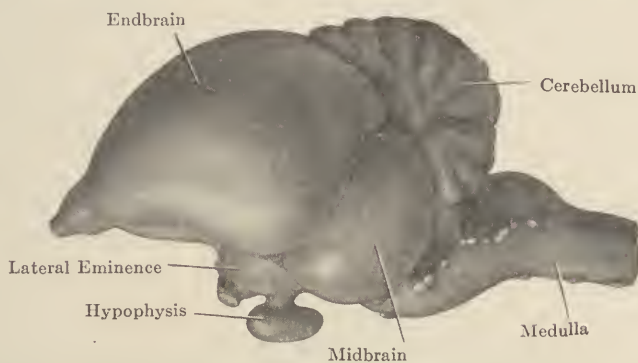


FIG. 400.—Brain of pigeon (*Columba*), illustrating the later phases in the process of telencephalization. The endbrain shows marked development.

thalamus, and from the corpus striatum. It sends fibers in all probability to the cerebral peduncle. The subthalamus comprises the *subthalamic body* of *Luy*s and the *two fields of Forel*, with a cephalic portion of the *red nucleus*

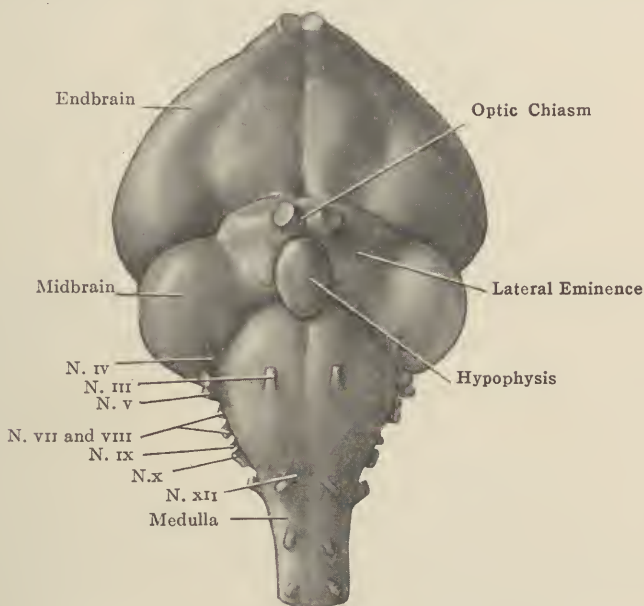


FIG. 401.—*Birds*: Structures in the floor of the third ventricle of the pigeon (*Columba*) indicated in heavy type.

and adjacent gray matter which is continued dorsally into the *substantia nigra*.

The addition of the neothalamus does not change the functional responsibilities of the interbrain in its relation to the emotions and instincts.

In fact it is probable that its added capacity as a sensory organ tends to amplify rather than diminish the importance of the thalamus in relation to the emotional sphere.

The Pars Metathalamica. This part of the interbrain comprises the corpus geniculatum laterale and corpus geniculatum mediale. The lateral geniculate body is the older of these two structures. It makes its first appearance in the selachians, gradually increases in prominence, and reaches its most conspicuous development in the mammals in consequence of the telencephalization of the optic pathway. It acts as a relay station for visual fibers, and assists in conveying visual impulses from the retina to the visual area of the cerebral cortex.

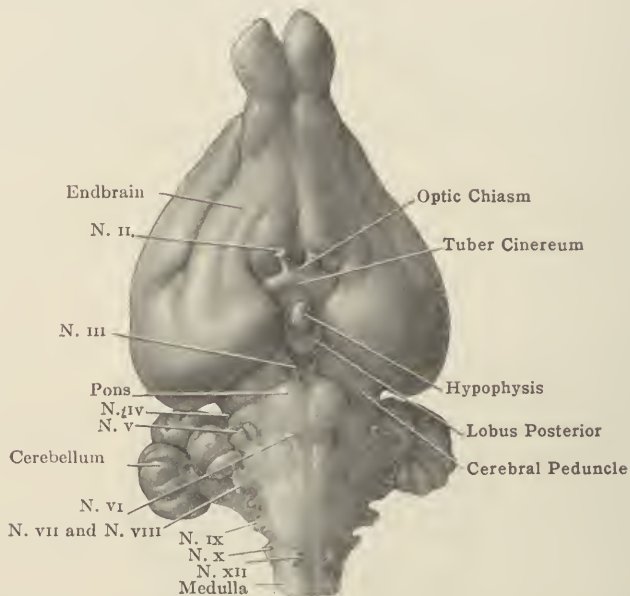


FIG. 402.—*Mammals*: Structure in the floor of the third ventricle of the rabbit (*Lepus*) indicated in heavy type.

The mesial geniculate body makes its appearance coincident with the development of the acoustic portion of the ear. It serves as a relay station in the auditory pathway.

Summary Concerning the Significance of the Interbrain. The interbrain develops from the dorsal and ventral areas of the *ectoptic zone* of Schulte. It consists of four parts: *Pars hypothalamica*, *pars epithalamica*, *pars thalamica*, and *pars metathalamica*.

I. THE *PARS HYPOTHALAMICA* consists of five distinct structures:

1. The *optic chiasm*, which is constant throughout the vertebrate series and represents a complete or partial crossing of the optic fibers.

2. The *lobi inferiores*, which appear in the fish and amphibia as two bilateral lobes connected with the sense of taste. These lobes become much reduced in the higher vertebrates, where they appear as the *postchiasmatic eminence* (*bulbus infundibuli*) and *eminentiæ laterales* of the *tuber cinereum*.

3. The *infundibular region*, which in fish and amphibia gives rise to the neural portion of the *hypophysis cerebri* and the *saccus vasculosus*. In all higher vertebrates the *saccus vasculosus* does not appear. The neural portion of the hypophysis becomes the infundibular stalk and infundibular process. The infundibular process and stalk are invested by the glandular tissue of the *pituitary gland*.

4. The *postinfundibular eminence*, which is constant in the vertebrate series but does not correspond to the *saccus vasculosus*. Its functional significance is unknown.

5. The *lobus posterior*, which in fish is the caudalmost element in the floor of the interbrain. In higher vertebrates it is subdivided into two equal



FIG. 403.—Brain of rabbit (*Lepus*) illustrating the late phases in the process of telencephalization as shown in the marked development of the endbrain and the disappearance of the midbrain from surface view.

bodies, the *corpora mammillaria*, which act as a way station in the efferent pathway from the olfactory portion of the brain.

II. THE PARS EPITHALAMICA consists of the derivatives of three arches:

1. The *paraphyseal arch* (properly belonging to the telencephalon), which gives rise to the paraphysis and lateral tela chorioidea in lower vertebrates. The paraphysis has the character of a glandular structure. It is vestigial or absent in birds and mammals.

2. The *postvelar arch*, which gives rise to the superior tela chorioidea forming the chorioid glands of the third ventricle. It is present in all vertebrates.

3. The *epiphyseal arch*, which gives rise to the pineal eye or eye-like structure of cyclostomes, amphibia and the primitive reptiles. This formation is absent in more recent reptiles, birds and mammals. In these animals the epiphyseal arch forms the pineal gland, an organ of internal secretion.

III. THE PARS THALAMICA comprises the paleothalamus, neothalamus and subthalamus.

1. The *paleothalamus* serves as the center for correlation of sensory impressions in the interest of primitive emotion and emotive expression.

2. The *neothalamus* is an addition to the pars thalamica appearing in mammals only. It establishes relay stations for the pathways of somesthetic and visual sensibility on their way to the brain.

3. The *subthalamus* is situated in the wall of the third ventricle ventral to the paleothalamus. Its functions are not well understood.

IV. THE PARS METATHALAMICA comprises the mesial and lateral geniculate bodies.

1. The *corpus geniculatum laterale* is relatively the more ancient. It made its appearance in selachians and has become progressively more important in mammals. It serves as a relay station in the optic pathway.

2. The *corpus geniculatum mediale* made its appearance in amphibia coincident with the development of the auditory portion of the ear. It serves as a relay station in the auditory pathway.

CHAPTER XXXII

THE INTERBRAIN

ANATOMY AND EMBRYOLOGY OF THE DIENCEPHALON

Situation, Boundaries and Relations of the Interbrain. The diencephalon occupies the mesial portion of the middle fossa of the skull. It presents for examination a ventral, dorsal, two lateral surfaces, a cephalic and caudal extremity. It forms the boundary of the third ventricle, which is connected through the aqueduct of Sylvius with the fourth ventricle and by means of the two foramina of Monro with the lateral ventricles. The ventral surface of the diencephalon is in contact with the optic groove, postoptic eminence and the diaphragma sellæ. A portion of it protrudes below the diaphragm into the sella turcica. This is the *hypophysis cerebri*.

The dorsal surface is in relation by its smaller mesial portion with the velum interpositum, the body of the fornix and the corpus callosum, which lie above it. The more lateral portion of the dorsal surface projects into the body of the lateral ventricle.

The lateral surfaces are concealed from view because of their intimate relation to the endbrain. Either lateral surface of the interbrain is in actual contact in its lower portion with the fibers of the internal capsule and in its upper portion with the body and tail of the caudate nucleus. The cephalic extremity of the diencephalon is in relation with the anterior pillars of the fornix. Its inferior portion is continued into the telencephalic part of the third ventricle, *the aula*.

PARTS OF THE INTERBRAIN

The diencephalon comprises four distinct divisions:

1. The hypothalamus (*pars hypothalamica*).
2. The epithalamus (*pars epithalamica*).
3. The thalamus and subthalamus (*pars thalamica*).
4. The metathalamus (*pars metathalamica*).

The Hypothalamus. The hypothalamus consists of all the structures constituting the ventral surface of the diencephalon. These include: (1) The *optic chiasm*; (2) the *postchiasmatic eminence*; (3) the *infundibular process* and *stalk*; (4) the *postinfundibular eminence*; and (5) the *mammillary bodies*.

The *optic chiasm* is the most cephalic structure in the hypothalamus. It consists of a small mass of medullary substance quadrilateral in form and elongated in its transverse diameter. Its size varies in man from 12 to 14 mm. Its cephalo-caudal diameter is from 5 to 6 mm. It presents four angles. Its two cephalic angles receive the convergent fasciculi which form the optic nerves; its two caudal angles give rise to two large divergent fasciculi which constitute the optic tracts. The optic chiasm represents the

crossing of the optic pathway or *decussation of the visual fillet*. It is formed by the meeting of the convergent optic fibers which undergo partial decussation in man. It rests upon the olivary eminence and is embraced between the internal carotid arteries. The optic fibers entering the chiasm number about half a million (according to Salze). Those fibers coming from the nasal or

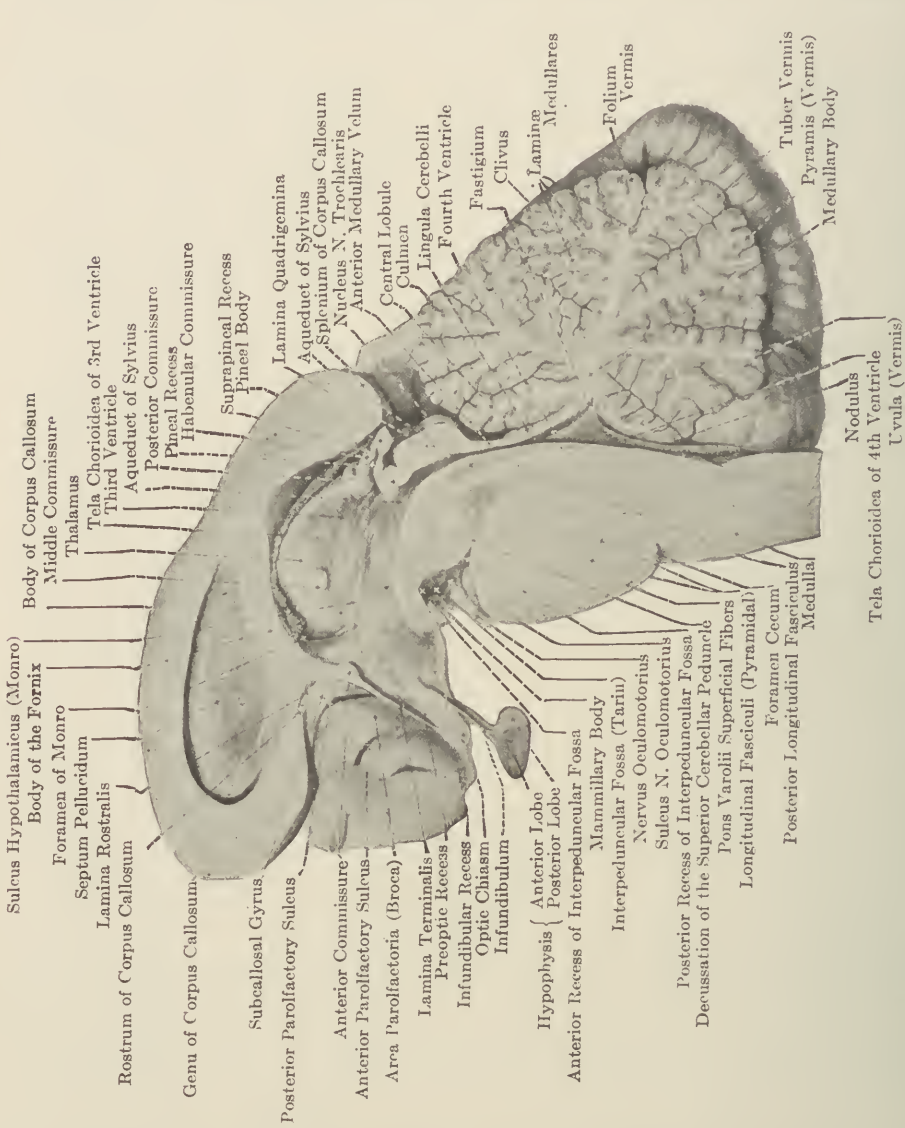


FIG. 404.—Median section through brain stem, right half, viewed from the left; only a very small part of the brain mantle is shown. (*Spaltholz*.)

inner half of each retina undergo complete decussation and enter the mesial part of the opposite optic tract. Those fibers coming from the temporal or outer half of the retina continue into the lateral part of the optic tract of the same side. A commissural loop connecting the two optic nerves has been described, but its existence has not been generally accepted. In some cases

the decussation of the optic fibers is complete even in man. In most of the lower vertebrates the optic fibers undergo complete decussation in the chiasm. This is the condition even in a few mammals, such as the guinea-pig and the mouse. In very rare instances the optic decussation is absent altogether and the optic fibers pass directly to the tract on the same side.

The chiasm is not composed entirely of fibers arising in the retina. In its dorsal portion there is a bundle known as *Gudden's commissure* (*commissura inferior*) which passes along the mesial side of the optic tract, circles around the caudal angle of the commissure and enters the opposite tract. These fibers have no connection with the pathway for light impulses, but are probably related to the mesial geniculate body and the inferior colliculi of the midbrain. In addition to these fibers certain strands in the optic chiasm arise in a plane parallel to that of Gudden's tract, but separated from it by a thin layer of gray matter. These fibers form *Meynert's commissure* (*commissura superior*). The origin and destination of these fibers are not known. The fibers are regarded by some as continuations of the mesial fillet which, after decussation, pass to the globus pallidus of the lenticular nucleus of the opposite side. According to others they end in the corpus subthalamicum. Commissural fibers constituting the *commissura ansata* descend from the floor of the third ventricle and from the peduncle of the septum pellucidum by way of the lamina terminalis to the cephalic portion of the optic chiasm. Other fibers pass from the ventricular floor back to the chiasm. These fibers cross to the opposite side through the substance of the optic chiasm.

The Postchiasmatic Eminence (Tuber Cinereum). In man the postchiasmatic eminence differs from that of the lower vertebrates. It is much reduced in size and consists of a protuberance immediately caudal to the optic chiasm. This protuberance embraces the *bulbus infundibuli*, the *infundibular stalk*, and the *eminentiæ laterales*, which structures collectively constitute the tuber cinereum. The eminence as seen from the ventral surface of the brain is a median elevation in front of the mammillary bodies and between the optic tracts and cerebral peduncles. It consists of a thin layer of gray matter about 1.5 mm. in thickness. Its ventricular surface is convex and limits the most dependent portion of the third ventricle. It is continued forward into the optic chiasm as a part of the *suboptic lamina*. Caudally it is continuous with the corpora mammillaria and with the gray matter of the posterior perforated space. Near its ventral extremity and in the midline there is a small protrusion which consists of gray and white matter and passes through the aperture of the diaphragma sellæ. This is the stalk of the infundibular process. The portion of the tuber cinereum with which the stalk is connected is funnel shaped and often referred to as the *bulbus infundibuli*. Upon either side of the bulbus infundibuli the tuber cinereum presents two symmetrical enlargements constituting the *eminentiæ laterales*, which may be regarded as the vestiges of the inferior lobes of the lower vertebrates. Near its dorsal extremity and immediately

in front of the corpus mammillaria in the midline is a small saccular eminence which contains a recess of the third ventricle.

The tuber cinereum contains a small paired composite ganglion, the *nuclei tuberis*, and another pair of ganglia, the *nuclei supra-optici*. Little is known concerning their connections. Two commissural fasciculi enter into the formation of the tuber cinereum. These are the *fasciculus of Meynert* and the *fasciculus of the tuber cinereum*. The fasciculus of Meynert is situated above the optic chiasm. Its significance is still unknown. The fasciculus of the tuber cinereum described by Gudden is a small bundle of fibers which extends transversely from one side of the tuber cinereum to the other immediately below the third ventricle. Ventrally, it divides into two secondary

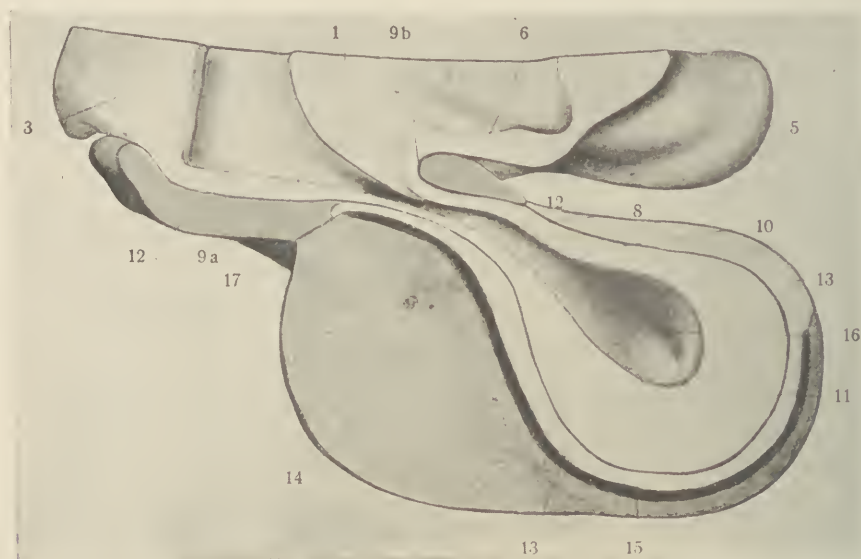


FIG. 405.—Reconstruction showing the relation of the hypophysis in the adult cat to the diencephalon (in sagittal view).

1. Third ventricle. 3, optic chiasm; 5, corpora mammillaria; 6, arca premammillaris; 8, Recessus infundibuli; 9, eminentia saccularis; 9a, ventro-cephalic surface of eminentia saccularis; 9b, Caudal surface of eminentia saccularis; 10, infundibulum; 11, processus infundibuli; 12, pars tuberalis; 13, Pars infundibularis; 14, pars distalis; 15, lumen residuale; 16, recessus processu infundibuli; 17, Recessus tuberis.

bundles, the internal and external fasciculi. The internal fasciculus passes toward the anterior pillar of the fornix, while the external fasciculus enters the inferior portion of the internal capsule. The significance of these connections is unknown.

The Stalk of the Infundibulum and Infundibular Process. The stalk of the hypophysis is a small strand of gray matter 4 to 6 mm. in length which projects from the most prominent portion of the tuber cinereum. Its angle of projection with the base of the brain varies from 60 to 85 degrees, its inclination being ventro-cephalad. It is cylindrical in shape except at the point of its attachment to the tuber cinereum where it is funnel-shaped. It tapers gradually to its inferior extremity, where it is continuous with the superior surface of the infundibular process. In fetal stages of all mammals

the stalk contains a tubular continuation from the third ventricle. This is present and persists for some months in the child. In the adult the entire stalk becomes solid. It connects the hypophysis with the floor of the brain. The stalk passes through the central aperture in the diaphragma sellæ and in this way connects with the infundibular process which lies below the diaphragm in the sella turcica. The infundibular process of the hypophysis is a portion of the brain which lies in the cavity formed by the sella turcica. It is the neural element in the hypophysis cerebri. This organ consists of two portions, a neural part or *infundibular process*, and a glandular part or *pituitary gland*. It is situated in the sella turcica, which it entirely fills. Its cephalic and caudal surfaces are in contact with the bony walls of the sella,

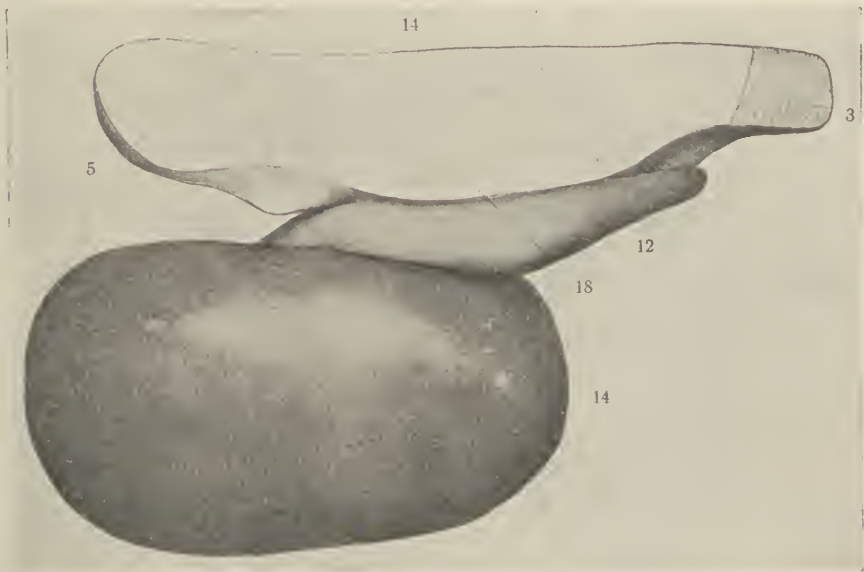


FIG. 406.—Reconstruction showing the relation of the hypophysis in the adult cat to the diencephalon (in lateral view).

3. Optic chiasm. 5. Corpora mammillaria. 12. Pars tuberalis. 14. Pars distalis. 18. Eminentia lateralis.

while its lateral extremities touch the internal walls of the cavernous sinus. The ventral surface is convex and rests upon the floor of the sella turcica, beneath which lies the sphenoidal sinus. The dorsal surface of the hypophysis is convex and in contact with the process of the dura mater forming the diaphragma sellæ. In shape the hypophysis cerebri is ellipsoid, having its largest diameter transversely. It is somewhat flattened cephalo-caudally. Its cephalo-caudal diameter is 8 mm.; its dorso-ventral diameter 6 mm., and its transverse diameter 12 to 15 mm. In weight the hypophysis cerebri varies from 3.5 to 4.5 gm. Its specific gravity is 1.0657. The hypophysis cerebri consists of two portions spoken of in human anatomy as the *anterior* and *posterior lobes*, the posterior lobe representing the infundibular process, the anterior lobe, the pituitary gland. The designations *infundibular process*

and *pituitary gland* afford a more consistent basis for a description applicable to all vertebrates.

The infundibular process is approximately one-third the size of the pituitary gland. It is situated caudal to the latter and in part separated from it by a small epithelial lined cavity which often contains colloid material and is known as the *residual lumen*. A firm attachment, however, persists between the two lobes by means of trabeculæ of connective tissue and neuroglial fibers.

The infundibular process consists largely of neuroglia-cells in which are scattered some cells of unusually large size. Occasionally the acini



FIG. 407.—Reconstruction showing the pars tuberalis of the adult cat separated from the rest of the hypophysis.

21. Infundibular aperture. 22. Dorsal surface of pars tuberalis.

from the glandular portion of the hypophysis extend backward into the infundibular process.

The pituitary gland consists of three portions:

1. The *pars distalis*, which is the largest part of the gland and consists of cells arranged in cords and acini. It has no direct contact with any part of the nervous system, from which fact it has been called the distal part.

2. The *pars infundibularis*, which in man and in most mammals surrounds the infundibular process upon all sides and forms the lining of the residual lumen.

3. The *pars tuberalis*, which in man invests the stalk of the infundibular process and spreads as a thin layer of glandular tissue in contact with the

bulbus infundibuli. In the lower mammals, the pars tuberalis is one of the most conspicuous portions of the gland, but in man it has been much reduced in size and prominence.

Each of the three portions of the pituitary gland is derived from the pouch of Rathke arising in the roof of the mouth. The histology of each part of the gland is so distinctive as to justify division of the pituitary gland into these three portions.

The Postinfundibular Eminence. This eminence has been described by Retzius as the "eminencia saccularis" because of its supposed relation to the saccus vasculosus in fish. Such interpretation, however, is incorrect. The eminencia saccularis has nothing in common with the saccular formation of the fish.

Corpora Mammillaria. These structures constitute the most caudal elements of the ventral surface of the interbrain. They are two in number, one upon either side of the midline. They appear as large, symmetrical protuberances, hemispherical in outline, measuring from 4 to 6 mm. in their transverse diameter and situated immediately caudal to the tuber cinereum. A sulcus separates the two bodies in the midline. The constituents of the corpora mammillaria will be discussed in the chapter on the histology of the interbrain.

The Epithalamus. In man the epithalamus constitutes the roof of the third ventricle and consists of two parts, the *tela chorioidea superior* and the *pineal gland*. The paraphysis does not make its appearance in the human embryo, with the possible exception of a small evagination situated cephalad of the velum transversum. The postvelar arch is represented by the extensive development of the *tela chorioidea superior*, while the epiphyseal arch gives rise to the pineal gland.

The Tela Chorioidea Superior or Velum Interpositum. This structure forms the roof of the third ventricle and is situated beneath the corpus callosum and the body of the fornix. It is a thin membrane, extending horizontally along the dorsal surface from one optic thalamus to the other. It has a triangular form with its base directed caudad and its apex cephalad. It presents two surfaces, two lateral borders, a base and an apex. The superior surface is convex from side to side and corresponds in its entire extent to the fornix, to which it is united by means of delicate trabeculæ and blood vessels. The inferior surface in its lateral portion is in contact with the dorsal surface of the optic thalamus. By its median portion it forms the roof of the third ventricle from which it is separated by the thin ependymal membrane. The ependyma in this region consists of a single layer of epithelial cells. The *tela chorioidea*, as in the case of all chorioid plexus, extends into the cavity of the ventricle. Its inferior surface presents two longitudinal prolongations, granular in appearance and reddish brown in color. These are the *plexus chorioides ventriculi*. At the cephalic extremity of the *tela chorioidea* each plexus is continuous through the foramen of Monro with the chorioid plexus of the lateral ventricle. The two distinct chorioid plexus of the third ventricle are often fused across the median line to form a single plexus.

The lateral borders of the tela chorioidea are continuous with the chorioid plexus of the lateral ventricle. They are lightly attached along the edges of the fornix and to the dorsal surface of the thalamus. The base of the tela chorioidea is situated between the splenium of the corpus callosum and the superior colliculus, where it is continuous with the pia mater covering these parts. The apex of the tela chorioidea corresponds to the angle formed by the bifurcation of the anterior pillars of the fornix. As in the case of the fourth ventricle, the tela chorioidea of the third ventricle is composed of two superimposed layers; the dorsal layer is in contact with the fornix, and the ventral with the epithelial lining forming the roof plate of the third

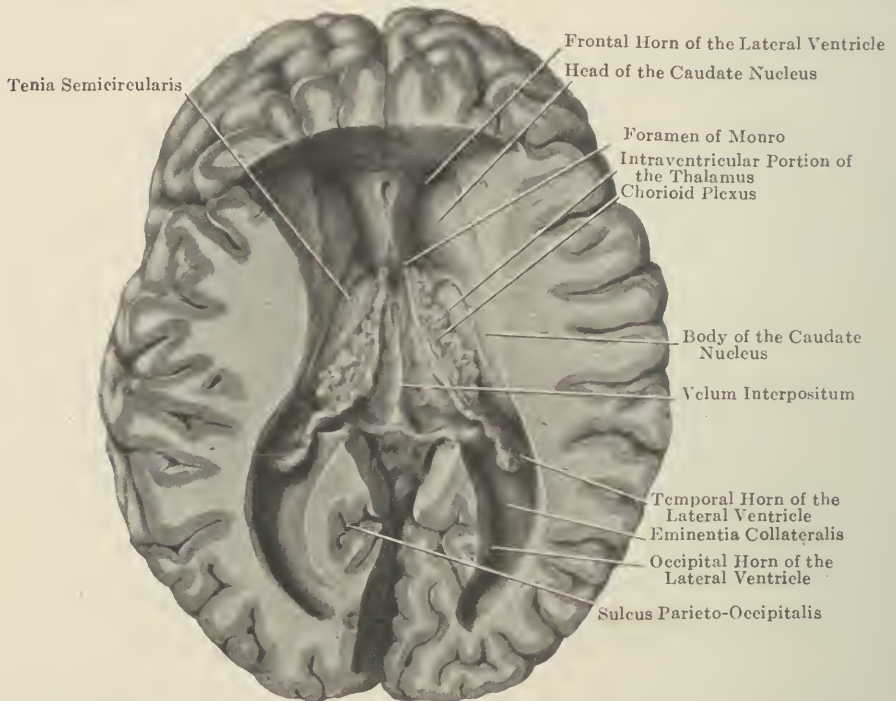


FIG. 408.—Horizontal section of the cerebrum showing the ventricular system, the chorioid plexus and the velum interpositum.

ventricle. These two layers are fused throughout their entire extent. At the base of the velum interpositum the layers separate, the dorsal layer being continuous with the pia mater over the corpus callosum, while the ventral layer passes over the superior colliculus and is continuous with the pia mater of the cerebellum. Between the two layers of the tela chorioidea there are extensions of connective tissue and continuations of the sub-arachnoid space. Through this space pass several arteries and veins. The arteries are derived from three small tortuous branches arising from three sources: (1) The superior cerebellar artery; (2) the posterior cerebral artery, and (3) the chorioid artery. These vessels follow a cephalo-caudal course. The veins are more important and result in the formation of two

large trunks, one on the right and the other on the left. These are the *veins of Galen* (*venæ Galeni*) which communicate with the *straight sinus* of the skull.

The Pineal Gland. The pineal gland is the second constituent in the human epithalamus. It is also known as the *epiphysis* or *conarium*. It is situated beneath the splenium of the corpus callosum and in the subpineal fossa between the two superior colliculi. The gland is held in this position by its adherence to the pia mater and also by certain prolongations which are attached to its base. In its contour the pineal gland resembles a pine cone from which it takes its name. It consists of a body, a base and an apex. Its body is considerably flattened; it is in relation above with the veins of Galen and the splenium of the corpus callosum; below with the longitudinal sulcus forming the subpineal fossa of the midbrain. Upon the side it is in relation with the chorioid plexus of the lateral ventricle, removal of which frequently detaches the pineal body from its connections with the brain. Its base is directed cephalad and consists of a dorsal and a ventral lamina which bound an accessory recess of the third ventricle, the *pineal recess*. Above the dorsal lamina a small extension of the third ventricle constitutes the *suprapineal recess*. The apex is directed caudad and is freely movable above the superior colliculi in the subarachnoid space. The dimensions of the pineal gland, as estimated by several observers, vary considerably. The transverse diameter varies from 4 to 8 mm.; the longitudinal diameter from 6 to 12 mm.; the dorso-ventral diameter from 4 to 6 mm. Its weight varies from 15 to 25 cg. Its specific gravity, according to Engel, is 1.047 to 1.050.

Relations of the Pineal Gland. According to some authorities the pineal gland is lodged between the two layers of the tela chorioidea superior. This description, however, is inaccurate. The pineal gland rests upon the ventral layer of the tela chorioidea, but has no relation to the dorsal layer which has already made its way over the splenium of the corpus callosum. The pineal gland is connected with the brain by means of several fasciculi of nerve fibers which are attached to its base. These fasciculi are called the *peduncles of the pineal gland* and are six in number, three upon either side. The dorsal peduncles are also called the *habenæ* or *reins*; they were described by early anatomists as the "*reins of the soul*," and the pineal gland was likened to a driver who, from this position, directed the operations of the mind. The *habenæ* arise from the lateral angles of the dorsal lamina; they are directed forward as far as a small triangular region, the *trigonum habenulæ*, and may be traced as a band of fibers attenuating as it proceeds cephalad to the junction of the superior and mesial surface of the optic thalamus. The *middle peduncles of the pineal gland* are also attached to the dorsal border at its base and are more feebly developed. They proceed forward and enter the posterior commissure to terminate in the substance of the optic thalamus. The *ventral peduncles* are generally but poorly defined; they arise in the lateral angles of the inferior lamina at the base and descend in front of the posterior commissure to end in the optic thalamus.

The Posterior Commissure. The most caudal constituent of the epitha-

lamus is the *commissura posterior cerebri*, which is a narrow but distinct cord-like band of white matter overlying the superior portion of the cephalic orifice of the aqueduct of Sylvius. It is partially masked by the habenular commissure and the ventral peduncle of the pineal gland. It extends for a short distance beneath the superior colliculi of the midbrain, but is a structure definitely connected with the interbrain. The posterior commissure provides the path by which fibers from various sources undergo decussation, although these connections established are not thoroughly understood at present.

The Thalamus and Subthalamus. The thalamus, also called the optic thalamus, consists of two large nuclei of gray matter situated upon either side of the third ventricle in front of the superior colliculi, caudal and mesial to the corpus striatum of the endbrain. Ventral to the thalamus and without any very sharp line of demarcation is the *subthalamus*.

The thalamus measures 35 to 40 mm. in length; its thickness is 18 to 22 mm., and its height 20 to 25 mm. In shape the thalamus is ovoid, with its larger extremity directed caudad and its long axis extending obliquely cephalo-caudally. It presents four surfaces and two extremities, namely, a dorsal, ventral, lateral and mesial surface, a cephalic and caudal extremity.

The dorsal surface of the thalamus is convex. It is brought to view by the removal of the tela chorioidea superior and the detachment of the cerebral hemispheres. Laterally it is bounded by the *optico-striate sulcus*, which separates it from the caudate nucleus. Its mesial boundary is the dorsal peduncle of the pineal gland which forms the *tenia thalami*. This surface presents a longitudinal groove directed obliquely cephalo-caudad in the long axis of the thalamus, the *chorioid sulcus*, so designated because of its relation to the chorioid plexus of the lateral ventricle. It divides the dorsal surface of the thalamus into two parts, a lateral triangular area which projects into the body of the lateral ventricle, and a mesial area which is extraventricular. The apex of the dorsal thalamic surface presents a rounded elevation, the *tuberculum anterius* (*corpus album subrotundum* of Vieussens), while the caudal extremity or base forms two protuberances, one on either side of the chorioid sulcus. The larger of these protuberances is the *pulvinar thalami*; the smaller is the *tuberculum posterius*.

In the dorso-mesial of this surface of the thalamus and occupying a plane considerably lower than the general level of the dorsal surface itself, is a small triangular region whose base is directed toward the pineal gland. This is the *trigonum habenulæ*. It measures 7 to 10 mm. in length and 3 to 4 mm. in width. Its mesial border is formed by the *tenia thalami*. The caudal portion of the trigonum habenulæ is elevated to form a small protuberance, hemispherical or ovoid in outline, the *ganglion habenulæ*.

The ventral surface of the thalamus is concealed from view by reason of its relation to the subthalamus with which it is continuous. No distinct line of separation exists between these two portions of the interbrain. The subthalamus, however, is an ancient portion of the diencephalon. It consists of three definite strata; 1, the field of Forel; 2, the *zona incerta*; and 3, the *corpus subthalamicum*.

The most dorsal of these three strata is the *field of Forel*; it is in direct relation with the ventral surface of the thalamus and consists of fine longitudinal fibers whose function is not clearly understood. Forel regards them as efferent axones of the red nucleus.

The *zona incerta* is situated ventral to the field of Forel and extends transversely from the lateral wall of the third ventricle to the internal capsule. It is a direct continuation of the *formatio reticularis* of the midbrain and consists of gray matter and some fine nerve fibers. The cephalic extremity of the red nucleus extends into its caudal portion. Cephalad the *zona incerta* is continuous into the *substantia innominata* of the endbrain.

The *corpus subthalamicum*, or body of Luys, described by this anatomist in 1865, is lenticular in form, grayish in color, and occupies a horizontal

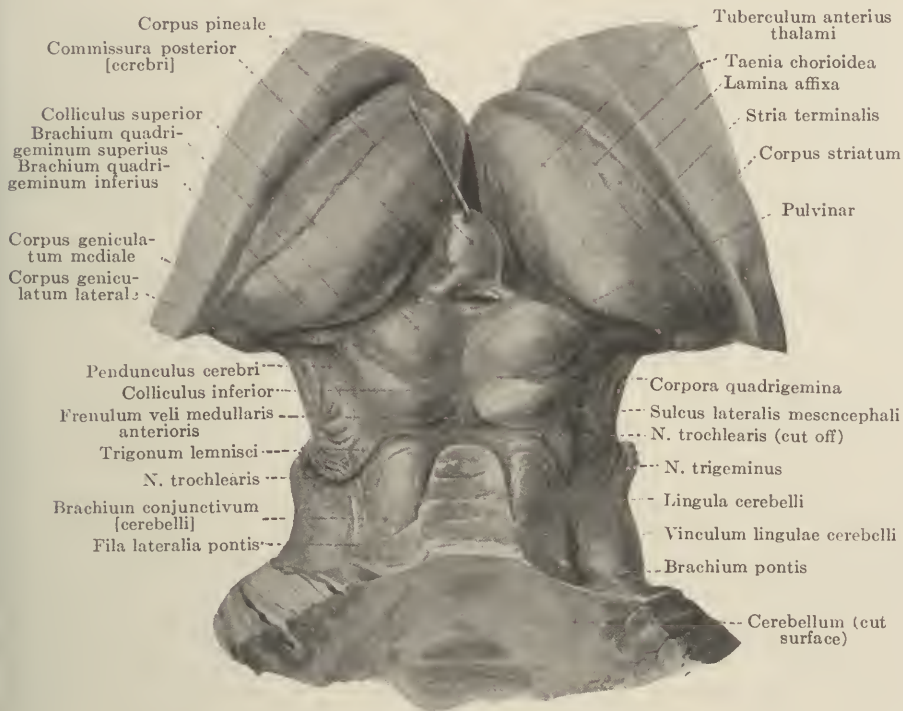


FIG. 409.—The optic thalamus viewed from behind. (Déjerine.)

position beneath the *zona incerta*. It measures from 10 to 12 mm. in length and from 3 to 4 mm. in width. Its superior surface is convex and in contact with the *zona incerta*. Its inferior surface is also convex and for a distance is in contact with the continuation of the *substantia nigra*.

The mesial surface of the thalamus, in its caudal third, is fused with the lateral aspect of the mesencephalon in the region of the superior colliculus. In its cephalic two-thirds the surface is free and enters into the formation of the lateral wall of the third ventricle. The mesial surface is limited ventrally by the *sulcus of Monro* which is the dividing line between the thalamus and subthalamus. This sulcus has been regarded as the cephalic continuation of the *sulcus limitans*. Such distinction, however, is probably inaccurate, inasmuch as the *sulcus limitans* comes to an end in the midbrain

in front of the nucleus oculomotorius where the basal plate of the neural tube ceases. The mesial surface of the thalamus gives attachment to the *middle commissure* or *commissura mollis* which unites the two optic thalami across the third ventricle.

The lateral surface of the thalamus is adherent to the endbrain throughout its entire extent. It is visible only upon cross section of this region. Ventro-caudally it is in relation with the fibers forming the posterior limb of the internal capsule. Ventro-cephally it is in relation with the putamen of the lenticular nucleus and the head of the caudate nucleus. Dorso-caudally it is in relation with the body of the caudate nucleus and the posterior limb of the internal capsule. Dorso-cephally it is in relation with the head of the caudate nucleus and the anterior limb of the internal capsule.

The cephalic extremity of the thalamus is somewhat elevated and lies in close relation to the head of the caudate nucleus. Its cephalic portion is crossed transversely by the anterior commissure.

The caudal extremity of the thalamus forms a large lateral protuberance, the *pulvinar*, and a smaller mesial enlargement, the *tuberculum posterius*.

The thalamus maintains an intimate relation with the caudate nucleus from which it is demarcated by the *optico-striate sulcus* and the *vena terminalis*.

The ganglion habenulæ, the trigonum habenulæ, the anterior tubercle, the mesial thalamic nuclei, and the subthalamus are all constituents of the paleothalamus. The other thalamic structures represent later acquisitions and constitute the neothalamus.

The Metathalamus. The metathalamus is an embryonic division of the diencephalon which gives rise to the mesial and lateral geniculate bodies. The *lateral geniculate body* is situated beneath the pulvinar, dorsal to the extremity of the optic tract from which it receives many fibers. It is fusiform in shape and about 10 mm. in length and 5 mm. in width. A large portion of the geniculate body is incorporated in the thalamus and appears as one of the prominent structures in cross section through this region of the brain. The lateral geniculate body consists of alternating layers of gray and white matter. Its medullary substance consists of fibers from the optic tract and axones which contribute to the formation of the optic radiation.

The *mesial geniculate body* is a fusiform structure. It is situated mesial to the lateral geniculate body and lateral to the inferior colliculus with which latter it is connected by means of the *brachium inferius*. The mesial geniculate body measures 10 mm. in length and 4 mm. in width. Like the lateral geniculate body it becomes incorporated as part of the thalamus and appears as one of the prominent elements in cross section in this region.

The Third Ventricle. The third ventricle is an unpaired median cavity situated between the two optic thalami. It comprises two subdivisions, a diencephalic and a telencephalic portion. It presents two lateral walls, a cephalic and caudal extremity, a floor-plate and a roof-plate. The ventricle contains a projection inward from the roof, the *tela chorioidea superior*, which secretes cerebrospinal fluid. It also contains the large middle com-

missure. Caudally the third ventricle communicates through the aqueduct of Sylvius with the fourth ventricle. Cephalically, through the foramen of Monro, it is in communication with the lateral ventricles. The diencephalic portion of either lateral wall is formed by the mesial surface of the thalamus and subthalamus, which are demarcated from each other by the *sulcus* of Monro. This sulcus at its cephalic extremity gives off two branches, one of which turns dorsally to terminate in the foramen of Monro, the other extends ventrally into the preoptic recess.

The telencephalic portion of the third ventricle, called the *aula*, is bounded laterally by the *substantia innominata*. Its cephalic extremity is bounded by the *lamina terminalis*. This part of the ventricle represents the unpaired portion of the ventricular cavity of the endbrain. The roof of the third ventricle is formed by the thin membranous layer of ependyma constituting the *membrana tectoria*. The pia mater in conjunction with the ependyma forms the tela chorioidea superior. Above the tela chorioidea are the body of the fornix and the corpus callosum. The caudal extremity of the third ventricle is bounded by the pineal body, the quadrigeminal plate of the midbrain and the tegmentum of the midbrain. At this extremity in the midline is a small circular opening, the *superior orifice* of the *aqueduct of Sylvius*. The floor of the third ventricle is formed by the optic chiasm, the tuber cinereum, the postinfundibular eminence, and the mammillary bodies.

Cavity of the Third Ventricle. The cavity of the third ventricle is much reduced in size by the presence of the commissura mollis which connects the two optic thalami across the midline. In connection with the third ventricle are certain accessory recesses, the most cephalic of which is the optic recess, a small extension of the ventricular cavity in front of the optic chiasm. It is in communication with a small canalicular extension of the ventricle situated above the optic chiasm and nerve, the *supra-optic canal*. The tuber cinereum contains a small recess in connection with the ventricle, the *recessus infundibuli*. Two recesses are connected with the third ventricle in the pineal region. These are the pineal and suprapineal recesses. By means of the two foramina of Monro the third ventricle communicates with the lateral ventricles, and by the aqueduct of Sylvius, with the fourth ventricle.

The cerebrospinal fluid secreted by the lateral and the third ventricles thus finds access to the fourth ventricle, whence it escapes through the foramen of Magendie and foramina of Luschke into the subarachnoid space.

The Commissura Mollis (Gray Commissure). This commissure consists of a mass of gray matter which to a large extent fills the third ventricle. Its transverse diameter measures 5 to 6 mm.; its cephalo-caudal diameter measures 8 to 10 mm. In thickness it is 3 to 4 mm. The commissure varies considerably in configuration as well as in its constancy in different individuals. It may be laminated, prismatic, triangular, or cylindrical. It is not uncommon to find the commissure double, while it is absent in as many as 10 to 15 per cent of normal individuals. It consists of nerve-cells and fibers. The cells appear to be entirely neuroglial; the fibers do not serve to connect one optic thalamus with the other, as the name of this structure would seem to imply.

EMBRYOLOGY OF THE DIENCEPHALON

The diencephalon develops from the dorsal and ventral portions of the *ectoptic zone of Schulte*. In the early stages of development, after closure of the neural tube, the prosencephalon is the most prominent vesicle of the brain. Its most conspicuous features are the two lateral evaginations forming the *optic vesicles*. These vesicles are surrounded by the ectoptic zone. They gradually become reduced in size and ultimately assume the form of an end vesicle, the *optic cup* and a stalk which retains connection with the ventral segment of the ectoptic zone. This stalk contains an extension of the ventricular lumen of the forebrain which extends into the optic cup. The

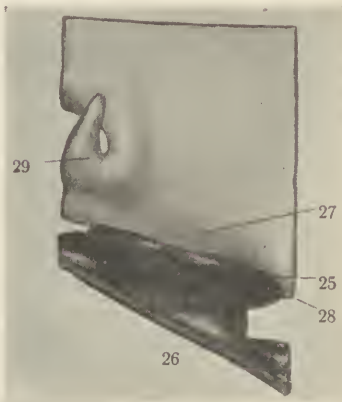


FIG. 410.—Reconstruction showing the relations of the hypophysis in a 7 mm. cat embryo.

25, Rathke's pocket. 26, Oral cavity. 27, Floor of diencephalon. 28, Infundibular process. 29, Optic recess.

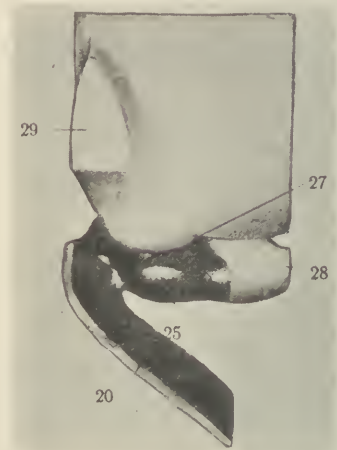


FIG. 411.—Reconstruction showing the relations of the hypophysis in a 10 mm. cat embryo.

20, Roof of mouth. 25, Rathke's pocket (buccal evagination). 27, Floor of diencephalon. 28, Infundibular process. 29, Optic recess.

stalk eventually serves as the framework through which the developing fibers of the ganglion cells of the retina pass to form the optic chiasm. The remnant of the original canal in the stalk of the optic vesicle persists in its proximal portion as the supra-optic canal. It communicates through the preoptic recess with the third ventricle. The remainder of the ventral segment of the ectoptic zone gives rise to the other chief constituent of the hypothalamus; namely, the infundibular region from which differentiates the tuber cinereum including, as it does in man, the bulbus infundibuli, infundibular process and stalk, the lateral eminences and the postinfundibular eminence. The infundibular process early comes into relation with a diverticulum from the roof of the mouth known as Rathke's pocket. From this diverticulum the pituitary gland develops. The caudal portion of the

infundibular region eventually migrates ventrally to fill a position in the sella turcica. Here it differentiates as the infundibular stalk and infundibular process. This process and stalk as well as a certain portion of the tuber cinereum become invested by glandular outgrowths from Rathke's pocket. The diverticulum of the mouth originally contained a large recess which communicated with the oral cavity. This recess is gradually constricted until but a slender neck remains connecting the main diverticulum with the roof of the mouth. Probably this connection represents the vestige of the bucco-neural duct which in ancestral vertebrates appears to have been a communication between the mouth cavity and the brain. This duct persists to the later stages of embryonic life. The oral diverticulum at an early

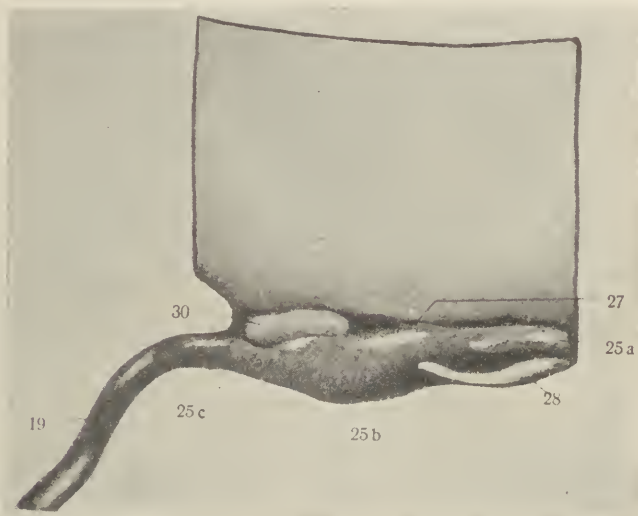


FIG. 412.—Reconstruction showing the relations of the hypophysis in a 14 mm. cat embryo.

19. Hypophyseal stalk. 25a. Caudal projection of buccal sac. 25b. Body of buccal sac. 25c. Neck of buccal sac. 27. Floor of diencephalon. 28. Infundibular process. 30. Tuberal process (anlage of pars tuberalis).

period gives off caudal processes which gradually invest the infundibular process and give rise to the *pars infundibularis* of the pituitary gland. The main body of the mouth pocket forms the *pars distalis* of the gland, and the remnant of the original cavity within it forms the *residual lumen*. Early in development two lateral outgrowths, situated one upon either side, and known as the tuberal sprouts, make their appearance. They soon begin to send extensions along the base of the brain, which gradually invest the infundibular stalk and extend upward upon the tuber cinereum. These tuberal sprouts eventually become confluent across the midline and form the *pars tuberalis* of the pituitary gland. Each of these three parts is embryologically distinct and each differs considerably in its histological character from the others.

The postinfundibular eminence appears late in the course of development as a small saccular protuberance in connection with the third ventricle. It often persists into adult life, although it is more commonly seen in children

and young infants. The mammillary bodies develop at first as an unpaired median ridge which subsequently becomes bilaterally symmetrical by the appearance of the *intermammillary sulcus*.

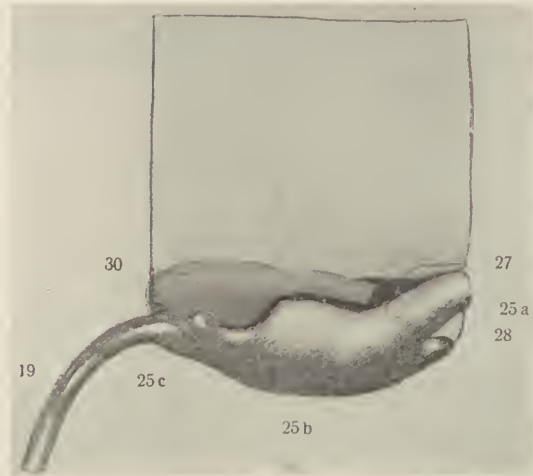


FIG. 413.—Reconstruction showing the relations of the hypophysis in a 25 mm. cat embryo.

19. Hypophyseal stalk. 25a. Caudal projection of buccal sac. 25b. Body of buccal sac. 25c. Neck of buccal sac. 27. Floor of diencephalon. 28. Infundibular process. 30. Tuberal process (anlage of pars tuberalis).

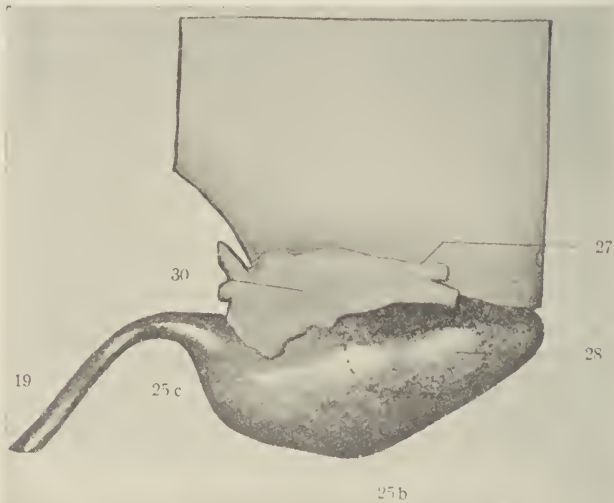


FIG. 414.—Reconstruction showing the relations of the hypophysis in a 31 mm. cat embryo.

19. Hypophyseal stalk. 25b. Body of buccal sac. 25c. Neck of buccal sac. 27. Floor of diencephalon. 28. Infundibular process. 30. Tuberal process (anlage of pars tuberalis).

The epithalamus in the early stages of development shows the three characteristic arches of the roof of the prosencephalon; namely, the paraphyseal, the postvelar and the epiphyseal arch. The paraphyseal arch in the human

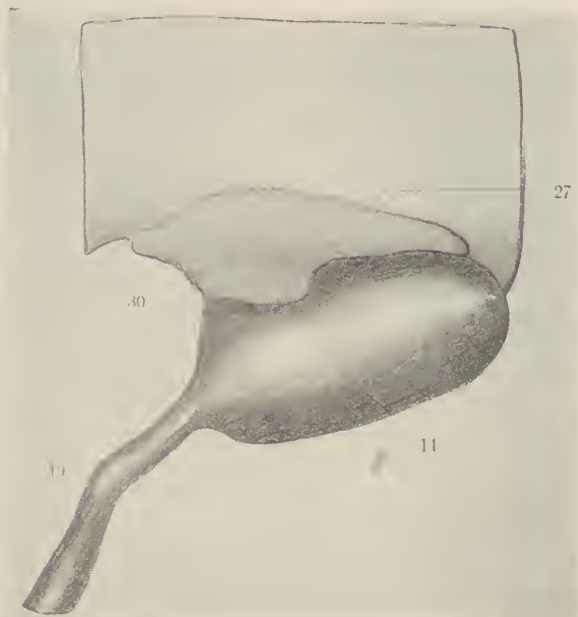


FIG. 415.—Reconstruction showing the relations of the hypophysis in a 51 mm. cat embryo.

14. Pars distalis. 19. Hypophyseal stalk. 27. Floor of diencephalon. 30. Tuberal process (anlage of pars tuberalis).

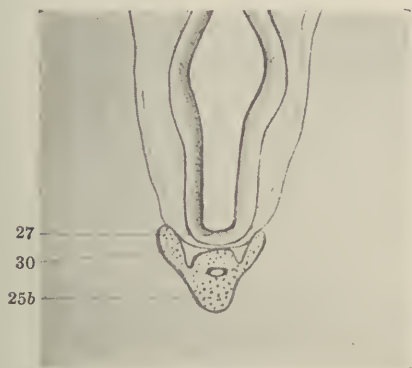


FIG. 416.—Projection drawing of a transverse section from a chick of 6 days and 22 hours showing the relation of the buccal sac to the diencephalon and the presence of the tuberal sprouts.

25b. Body of buccal sac. 27. Floor of diencephalon. 30. Tuberal process (anlage of pars tuberalis).

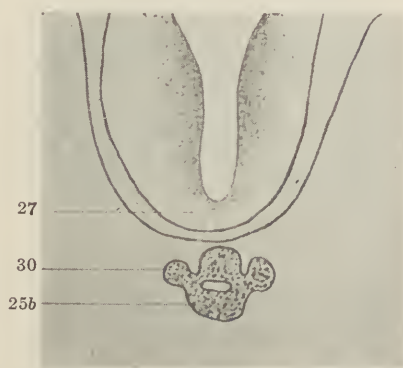


FIG. 417.—Projection drawing of a transverse section from a 17 mm. cat embryo showing the relation of the tuberal sprouts and the body of the buccal sac to the diencephalon.

25b. Body of buccal sac. 27. Eminentia saccularis. 30. Tuberal process (anlage of pars tuberalis).

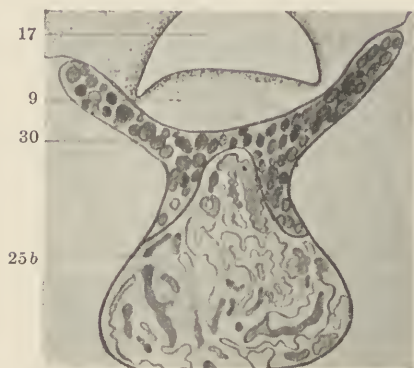


FIG. 418.—Projection drawing of a transverse section from a 51 mm. cat embryo showing the relation of the tubular sprouts and the body of the buccal sac to the diencephalon.

9. Eminentia saccularis. 17. Recessus tuberis. 25b. Body of buccal sac. 30. Tubular process (anlage of pars tuberalis).

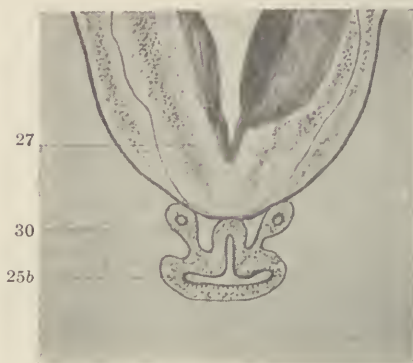


FIG. 419.—Projection drawing of a transverse section from a chick of 5 days and 20 hours, showing the relation of the buccal sac to the diencephalon and the presence of the tubular processes (anlage of pars tuberalis).

25b. Body of buccal sac. 27. Floor of diencephalon. 30. Tubular process.

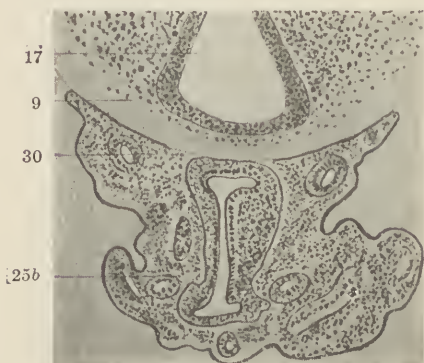


FIG. 420.—Projection drawing of a transverse section of a 100 mm. cat fetus showing the relation of the tubular sprouts and the body of the buccal sac to the diencephalon. In this stage the tubular processes have fused across the median line and the pars tuberalis thus formed has displaced the body of the buccal sac ventrally away from its original juxta-neural position.

9. Eminentia saccularis. 17. Recessus tuberis. 25b. Body of buccal sac. 30. Tubular process (anlage of pars tuberalis).

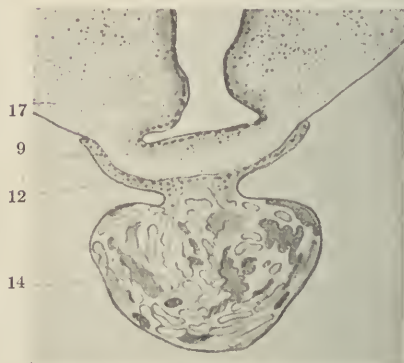


FIG. 421.—Projection drawing of a transverse section from a chick of 16 days showing the fusion of the tubular processes across the median line forming the pars tuberalis, with the consequent ventral displacement of the body of the buccal sac away from its original juxta-neural position

9. Eminentia saccularis. 12. Pars tuberalis. 14. Pars distalis. 17. Recessus tuberis.

embryo is a very transient structure. The lateral tela chorioidea are derived from this arch in man and the higher mammals. The postvelar or dorsal arch becomes flattened by the development of the corpus callosum and takes the position imposed upon it by the development of the tela chorioidea superior. The roof-plate, after acquiring an intimate connection with the inner layer of the pia mater, and gaining a marked vascularization, is thrown into numerous folds which form the chorioid plexus of the third ventricle. The epiphyseal arch presents but a single process, the *pineal organ*, there being no evidence of the development of the secondary parapineal organ noted in

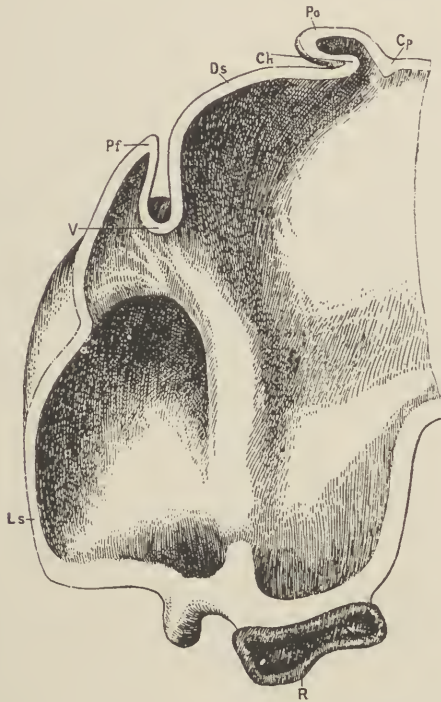


FIG. 422.—Reconstruction of a 30 mm. embryo of *thalassochelys caretta*. (*Tilney and Warren.*)

Ls—lamina terminalis; *Pf*—paraphysis; *V*—velum transversum; *Ds*—dorsal sac; *Ch*—commissura habenularis; *Pa*—epiphysis; *Cp*—posterior commissure; *R*—Rathke's pocket.

the lower vertebrates. The pineal organ at the end of the second month is invaded by cells from the roof-plate which soon differentiate into large cellular elements and assume definite aciniform arrangement with a high degree of vascularization. These acini have an appearance which justifies the opinion that they are glandular in nature and belong, like the pituitary gland, to the endocrinic system. The posterior commissure appears in the early stages of development as fibers crossing from one side to the other immediately in front of the superior colliculus and below the ventral peduncles of the pineal gland.

One of the earliest portions of the thalamus to be differentiated, is the

ganglion habenulae and its commissure, the *commissura habenularis*. This ganglion at first appears as a large ganglionic mass differentiated from the mantle zone. The more mesial nuclei of the thalamus make their appearance at about the same time, as is also true of the anterior tubercle of the thalamus.

At a relatively late stage in fetal development, two caudo-lateral evaginations develop which ultimately give rise to the metathalamus, including the mesial and lateral geniculate bodies.

The migration of cells from the mantle into the caudal portion of the thalamus above the evaginations from which the geniculate bodies are derived, forms the thalamus. In the late embryonic stages the lateral walls of the thalamus begin to thicken by a rapid increase in the cells of the mantle layer, and as the fibers from the mesial fillet and optic tract make their way into the thalamus, the lateral nuclei become differentiated and are ultimately distinguishable in their adult relations.

The region in which the subthalamus develops makes its appearance early in the differentiation of the lateral walls of the diencephalon, but it is not until the lateral nuclei of the thalamus proper are clearly discernible that it is possible to distinguish between the three strata of the subthalamus; namely, the fields of Forel, the zona incerta and the corpus subthalamicum.

CHAPTER XXXIII

THE INTERBRAIN

INTERNAL STRUCTURE AND HISTOLOGY OF THE DIENCEPHALON

The internal structure of the interbrain is best illustrated by cross sections through the following levels:

1. Through the mammillary bodies.
2. Through the tuber cinereum.
3. Through the optic chiasm.
4. Through the ansa lenticularis.
5. Through the anterior commissure.

The description of these sections requires the separate consideration of the constituents in each of the major divisions of the diencephalon, including: 1, the central gray matter; 2, the epithalamus; 3, the hypothalamus; 4, the thalamus; 5, the subthalamus, and 6, the basis diencephali.

Section at the Level of the Mammillary Bodies. 1. **THE CENTRAL GRAY MATTER.** The central gray matter at this level completely surrounds the third ventricle at its caudal extremity. It consists of a mass of small nerve cells. Near the lateral aspect of the central gray matter, a small group of cells constitutes the nucleus commissuræ posterioris. Lateral to this nucleus are the obliquely cut fibers of the *fasciculus retroflexus of Meynert*.

2. **THE EPITHALAMUS.** In this region the epithalamus consists of the base of the pineal gland in its connection with the roof-plate of the third ventricle. The basal portion of the gland is circular in outline and attached above the fibers of the posterior commissure to the roof. The pineal gland in man, as in other mammals, contains four types of cells:

(1) Large cells with extensive protoplasm and large vesicular nuclei. The nuclei of these cells stain deeply.

(2) Cells of large size but with vesicular nuclei which stain feebly.

(3) Smaller cells with large nuclei and a small amount of cytoplasm. The nuclei are intensely basophilic.

(4) Small cells with faintly staining nuclei which contain many granules.

The cells of these four varieties arrange themselves in a more or less distinctive manner. The larger epithelial elements are disposed in such a way as to form well defined acini or cords. Interspersed between these aciniform groups are convoluted chains or cords of cells consisting of both varieties of the larger type. The smaller cellular elements are scattered between the cords and the acini in an irregular manner. Trabeculæ of connective tissue give the impression of actual lobulation, although the lines of separation are most irregular and incomplete. A large number of long fibers are seen scattered among these cells and probably represent neuroglial processes or the terminal branches of sympathetic axones. The adult organ includes a variable



Fig. 423.—Cross section through the caudal limit of the mammillary bodies.

number of concretions called *brain sand* or *acervulus cerebri*. These concretions consist of laminated particles composed of calcium carbonate and phosphate enclosing some organic substance. They vary much in their dimensions.

The second element of the epithalamus is the posterior commissure whose anterior fibers appear at this level. The commissura posterior cerebri is a narrow band of white matter which overlies the cephalic orifice of the aqueduct of Sylvius. It is partially masked by the habenular commissure and the ventral peduncle of the pineal gland. It consists of fibers from various sources which cross at this point from one side to the other.

3. THE HYPOTHALAMUS. At this level it is represented by the mammillary bodies which appear as two hemispherical structures in the interpeduncular space. Histologically each mammillary body consists of two nuclei, the *principal* or *mesial nucleus* and a *lateral nucleus* which is much smaller and semilunar in shape. The mesial nucleus contains many cells densely crowded together and having a maximum diameter of from 12 to 14 micra. They are multipolar in form and possess long dendrites and fine tortuous axones. The lateral nucleus is situated along the lateral margin of the mammillary body adjacent to the *mammillo-peduncular sulcus*. It is in contact with the anterior pillars of the fornix which terminate in this region. Its cells are fusiform or triangular in shape and somewhat larger than those of the mesial nucleus. The maximum diameter varies from 18 to 24 micra. Their dendrites are numerous and branch frequently. The axone is short and its course difficult to follow.

Connections of the Mammillary Bodies. The mammillary body is connected with other parts of the brain by means of the mammillary peduncle, the anterior pillars of the fornix and the fasciculus of Vicq-d'Azyr. The peduncle of the mammillary body makes its way along the inner border of the cerebral peduncle as an isolated fasciculus of considerable size. It passes in a superficial position across the interpeduncular space, makes its way through the roots of the third nerve, and is believed by some authorities to end in the dorsal tegmental nucleus of Gudden or in its accessory nucleus situated in the neighborhood of the nucleus trochlearis. The fibers of the anterior pillars of the fornix end directly in both mammillary nuclei. Some of these fibers, however, pass dorsal to the nuclei by way of the supramammillary commissure to the mammillary body of the opposite side. The lateral portion of the mesial nucleus contains large cells whose axones form a distinct bundle of compact fibers. This bundle, after leaving the mammillary body, separates into two divisions. The first division is the *mammillo-thalamic tract* or *bundle of Vicq-d'Azyr*, which passes upward and forward to end in the anterior nucleus of the thalamus. This tract completes a connection between the cortical olfactory centers and the thalamus. The second division of this bundle arches backward and downward as the *mammillo-tegmental tract*. It is traceable through the tegmentum of the midbrain to the region of the inferior colliculus. In consequence of its connections, the mammillary body serves to bring the olfactory portion of the brain into

relation with the tegmentum of the midbrain and probably consummates a connection with the nuclei of the cranial nerves which serves in the interest of selecting and procuring food.

4. THE THALAMUS. The paleothalamus at this level presents the ganglion habenulæ situated in the caudal portion of the trigonum habenulæ. Histologically this ganglion consists of two groups of cells, a mesial group and a lateral group. The cells of the mesial group measure from 10 to 15 micra in diameter and are arranged in clusters forming the habenular glomeruli. The cells have two or three dendrites and an axone usually connected with the body of the cell, but occasionally derived from one of the dendrites. These axones enter into the formation of the *fasciculus retroflexus of Meynert*. The cells in the lateral group are much larger elements measuring from 20 to 26 micra in diameter. They are fusiform or polygonal in shape, have several long branching dendrites and axones which enter the fasciculus retroflexus of Meynert. The afferent fibers coming to the ganglion habenulæ constitute the *stria medullaris* or the *tenia thalami*. This structure consists of fibers arising for the most part in the olfactory lobe, but in part taking origin in the anterior nucleus of the thalamus. Some of these fibers do not end in the ganglion habenulæ of the same side, but cross to the opposite ganglion by way of the superior or habenular commissure. The efferent fibers from the ganglion constitute the fasciculus retroflexus of Meynert, which descends obliquely to the interpeduncular space and ends in the interpeduncular ganglion of Ganser. The ganglion habenulæ, therefore, is part of the olfactory projection system which connects the olfactory lobe with the tegmentum of the midbrain, whence impulses pass to the cranial nerve nuclei and perhaps also to the ventral gray columns of the spinal cord.

The most lateral portion of the thalamus corresponds to the recent acquisitions constituting the neothalamus. This structure consists at this level of four distinct nuclei. The largest and most dorsal of these is the *nucleus of the pulvinar*, ventro-mesial to which is the *nucleus lateralis*. Ventro-lateral to the lateral nucleus is the *nucleus lateralis ventralis externus*, and ventral to both of these nuclei the *nucleus arcuatus thalami*. All of these nuclei constitute relay stations in the major sensory pathways. The nucleus lateralis is also spoken of as the *sensory nucleus of the thalamus*. In it end the fibers of the mesial, trigeminal and spinal fillets. In this way the three major pathways of sensibility in the body, including both discriminative and affective qualities, receive relays in this nucleus. Its cells are stellate and vary from 20 to 22 micra in diameter. There are also other cells of smaller diameter, varying from 12 to 14 micra. The axones of the large cells are long and enter into the thalamo-cortical tract, constituting the final link in the sensory pathway to the cortex. The smaller cells have short axones which distribute themselves exclusively to the confines of the nucleus.

The pulvinar is a nucleus which is small in some of the lower mammals, but assumes marked proportions in man. It occupies the dorso-lateral extremity of the thalamus and is situated beneath the *stratum zonale*. The nerve cells contained in this substance morphologically resemble the

cells in the lateral geniculate body. They have long axones which enter into the formation of a central tract and ultimately become part of the optic radiation. It is a question, however, whether the pulvinar as a relay station in the optic pathway plays as important a part as the lateral geniculate body. In any event, lesions of it are not so frequently accompanied by hemianopsia.

The *nucleus arcuatus thalami* receives fibers from the mesial fillet for which it serves as a relay. It is in close relation to the central medullary lamina of the thalamus and receives a prolongation of the central sensory tract of the trigeminal nerve. Its cells are stellate or fusiform, the axones are tortuous and enter into the formation of the thalamo-cortical pathway connecting the thalamus with the cerebral cortex. A small accessory arcuate nucleus is situated caudal to the chief lateral nucleus immediately in front of the corpora quadrigemina. Its significance is probably similar to that of the lateral arcuate nucleus.

The external ventro-lateral nucleus contains cells which are disposed in a large group. They are relatively large fusiform or triangular elements with several richly branching dendrites. Some authorities consider the central ventro-lateral nucleus as one of the older portions of the thalamus.

Tracts of the Thalamus. The most important tracts in the thalamus are those which establish the final links in the sensory pathways. The connection between the pulvinar which contributes its fibers to the retrolenticular portion of the internal capsule, constitutes a part of the *optic radiation*. The continuation of the great somatic sensory pathway receives a relay in the lateral nucleus and also in the nucleus arcuatus. Fibers from the red nucleus extend beneath the nucleus arcuatus toward the thalamus and establish a rubro-thalamic connection. Some of these fibers may pass by the thalamus and reach the cerebral cortex, thus determining a rubro-cortical tract.

5. THE SUBTHALAMUS. The subthalamus at this level presents the cephalic extremity of the nucleus ruber surrounded by its dense capsule of nerve fibers. This nucleus consists of a dorsal accessory and a principal nucleus. The accessory nucleus is separated to some degree from the main portion of this nuclear collection by the descending fibers of the fasciculus retroflexus of Meynert. The cells and fibers of the nucleus ruber have already been described. Immediately ventral to the nucleus ruber is the cephalic continuation of the substantia nigra.

Lateral to the substantia nigra is a small compact nucleus in contact ventrally with the dorsal fibers of the basis diencephali. This is the corpus subthalamicum, also known as the corpus Luysi. The cells in this nucleus are fusiform, triangular and polygonal in shape and are disseminated without definite arrangement throughout the entire mass of the nucleus. The dendrites of the cells are long and have many branches. The axones are difficult to follow to their destinations. The afferent fibers which reach this nucleus are in part collaterals and in part terminal branches of axones. The collaterals and terminal fibers seem to have a connection with the cerebral peduncles.

Interposed between the corpus subthalamicum and the red nucleus is a small quadrilateral zone extending transversely across the section, the *zona incerta*. This zone contains a nuclear structure made up of small triangular cells with small branched dendrites. The axones descend from the nucleus but their destination is not known.

6. BASIS DIENCEPHALI. The basis of the diencephalon in the mid-brain consists mainly of three chief groups of fasciculi, the most mesial of which is the parieto-temporal pallio-pontile tract, the most lateral constituent being the frontal pallio-pontile tract while the intermediate group is the pyramidal system. The basis at this level is more obliquely disposed than in the midbrain, the lateral portion occupying a more cephalic position and also being in relation with a small part of the optic tract.

Section at the Level of the Tuber Cinereum. 1. THE CENTRAL GRAY MATTER. The ventricle at this level has increased much in its dorso-ventral extension and now exists as a considerable cleft between the opposing masses of the thalami. The central gray matter is diffuse and consists of small nerve elements covered by a single layer of ciliated ependymal epithelium.

2. The EPITHALAMUS. At this level it consists of a thin membranous roof thrown into many reduplications and in connection with the pia mater forming the *superior tela chorioidea*. The actual roof of the ventricle is formed by the thin ependymal layer constituting the *membrana tectoria ventriculi tertii*.

3. The HYPOTHALAMUS. This consists of the tuber cinereum, dorsal to which and incorporated in its substance is the cephalic extremity of the mammillary body. At this level the mammillary body presents the continuation of its large mesial nucleus, extending from which is the beginning of the mammillo-thalamic tract (the fasciculus of Vieq-d'Azyr) also known as the *fasciculus princeps* of the mammillary body. Lateral to the mesial mammillary nucleus are the fibers of the anterior pillars of the fornix about to terminate in the mammillary nuclei.

The tuber cinereum consists of three nuclei, a cephalic or principal nucleus, a caudal nucleus and a dorsal nucleus. The cells in the principal nucleus are ovoid or fusiform in shape and from 12 to 15 micra in diameter. Their dendrites ramify in all directions. The axones are small, give off many collaterals, and enter the region of the subthalamus. The caudal or accessory nucleus of the tuber cinereum consists of elongated and fusiform cells with branched dendrites. The axones may be traced as far as the aqueduct of Sylvius. Their exact destination is unknown. The dorsal nucleus of the tuber cinereum consists of fusiform and spherical cells. The cells have short dendrites whose axones are long and sinuous, but limit themselves to the confines of the nucleus. Two small supra-optic nuclei situated lateral to the dorsal nucleus have been described by some authorities. These nuclei, however, are not always well defined. It is possible that they may give rise to the fibers which enter into Gudden's commissure and accompany the optic tracts.

The most dependent portion of the tuber cinereum forms the *bulbus*

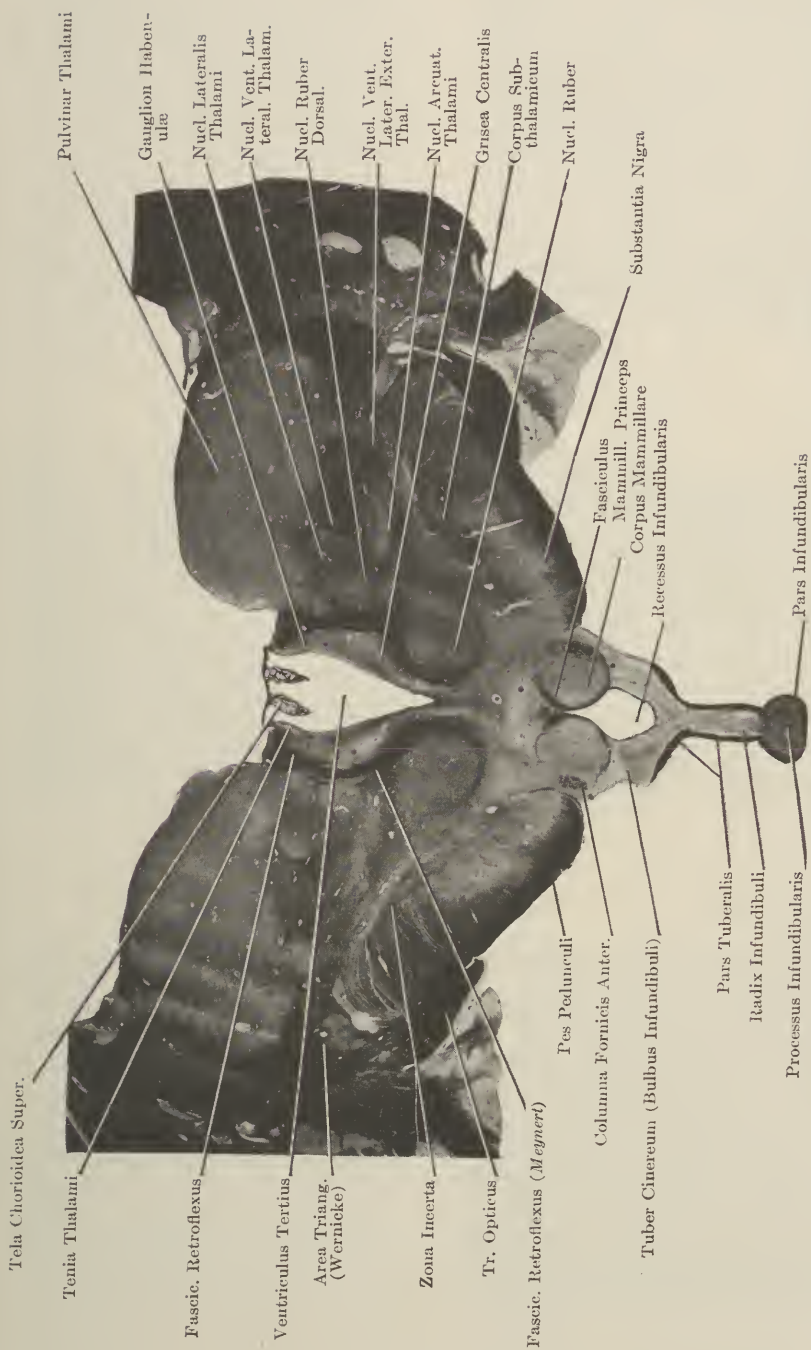


FIG. 424.—Cross section through the interbrain at the level of the tuber cinereum.

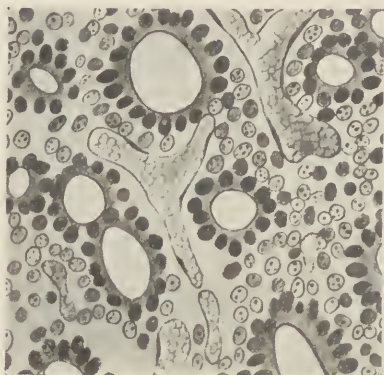


FIG. 425.—Projection drawing showing histological character of the pars tuberalis in the adult cat.

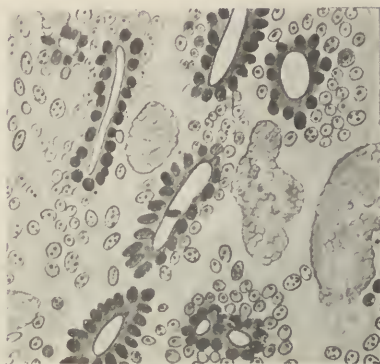


FIG. 426.—Projection drawing showing histological character of the pars tuberalis in the adult dog.

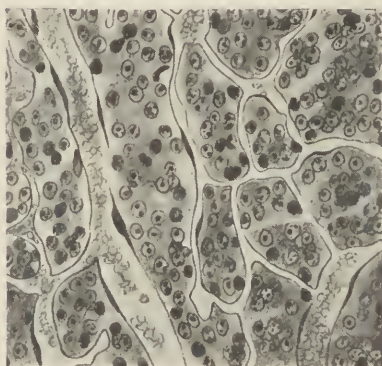


FIG. 427.—Projection drawing showing histological character of the pars distalis in the adult cat.

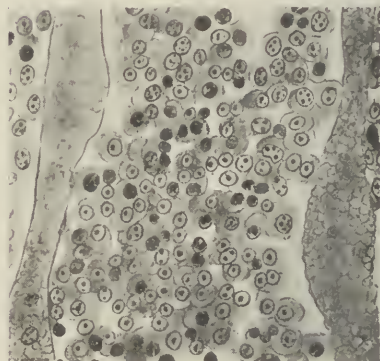


FIG. 428.—Projection drawing showing histological character of the pars distalis in the adult dog.

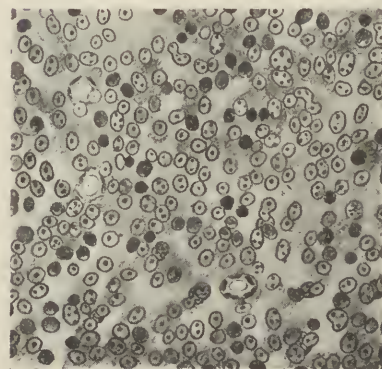


FIG. 429.—Projection drawing showing histological character of the pars infundibularis in adult dog.

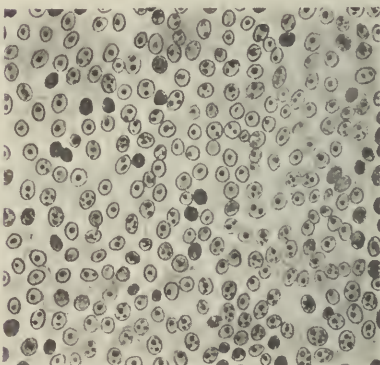


FIG. 430.—Projection drawing showing histological character of the pars infundibularis in adult cat.



Fig. 431.—Cross section through the interbrain at the level of the optic chiasm.

infundibuli, from the apex of which projects the infundibular stalk. The stalk consists of neuroglial cells with some connective tissue trabeculæ derived from the pia which invests it. The infundibular stalk connects with the infundibular process at its ventral extremity. This process is usually called the *posterior lobe of the hypophysis cerebri*. It consists of neuroglia with some connective tissue trabeculæ, and is attached to the pituitary gland. A small cleft intervenes between the neural and glandular portions of the hypophysis. This is the residual lumen.

The pituitary gland itself consists of three portions. The *pars distalis* consists of cell-cords and acini. It contains both acidophilic and basophilic cells. The *pars infundibularis* invests the infundibular process and consists of a stratum, four or five layers thick, of basophilic cells. Surrounding the infundibular stalk and in contact with the tuber cinereum is a layer of cells representing a conspicuous part of the pituitary gland in the lower mammals, the *pars tuberalis*. This portion of the gland contains basophilic cells which are larger than those in the *pars infundibularis* or in the *pars distalis*, and tend to be arranged to form small acini.

4. THE THALAMUS. At this level the older portion of the thalamus presents itself as the trigonum habenulæ, which is limited mesially by the tenia thalami, the fibers of which represent a continuation of the connection between the olfactory lobe and the ganglion habenulæ. The newer portion of the thalamus at this level is almost entirely occupied by the *nucleus lateralis*, ventro-mesial to which is the *nucleus arcuatus thalami*, and ventro-lateral the *nucleus ventro-lateralis externus*.

5. THE SUBTHALAMUS. The subthalamus contains the cephalic extremity of the red nucleus and the continuation of the cephalic portion of its capsule. Ventral to the red nucleus are the zona incerta and the fields of Forel. A small nucleus situated between these two fields is known as the *nucleus interstitialis* of Forel or the *interstitial nucleus of Forel's field*. Ventral to the field of Forel is the corpus subthalamicum, now much increased in size and resting upon the dorsal aspect of the basis diencephali. A small amount of the substantia nigra is seen partially incorporated with the mesial bundles of the basis.

6. THE BASIS DIENCEPHALI. This structure consists of the same constituents at this level as in the one immediately below. One marked change, however, has occurred in the arrangement of the fibers, namely, the parieto-occipito-temporo-ponto-cerebellar constituent has now assumed a vertical course, so that it lies between the lateral nucleus of the thalamus and the caudal extremity of the lenticular nucleus. Ventral to the basis are the longitudinal fibers of the optic tract, some of which are just beginning to converge toward the optic chiasm.

Section at the Level of the Optic Chiasm. 1. THE CENTRAL GRAY MATTER. At this level the arrangement of the central gray matter is the same as in the levels below, there being no specialized collections of cells forming separate nuclei. A single layer of ependymal epithelium forms the lining of the ventricle.

2. THE EPITHALAMUS. This portion of the diencephalon consists of the membrana tectoria which enters into the formation of the *superior tela chorioidea*.

3. THE HYPOTHALAMUS. This portion of the interbrain is represented by the optic chiasm and certain accessory commissures. The optic chiasm in man is a partial decussation in the pathway of vision. In this regard it is similar to the decussation of the mesial and lateral fillets which have been termed respectively the *somatic fillet* and the *auditory fillet*. This optic decussation may be called the *visual fillet*. Although the second cranial nerve is termed the optic nerve, it is in the strict sense a tract. Because of the peculiar circumstances attending the development of the eye, it has assumed a position somewhat distinct from the usual incorporation of such tracts within the mass of the white matter of the neuraxis. The optic nerve actually corresponds to the fibers of the somatic fillet before their crossing; the chiasm represents the fillet decussation, and the optic tract is similar to the continuation of the somesthetic pathway after decussation has taken place. According to Salzer's enumeration, there are half a million fibers in the optic nerve. The majority of these, about three hundred thousand, cross in the optic chiasm. The remainder establish direct connections and do not cross in the chiasm. This rule applies to man and those animals endowed with binocular vision. The decussation of the chiasm is partial in man, ape, dog, cat and rabbit, but complete in the guinea-pig. Among the birds, the owl seems to have binocular vision, yet the chiasm represents a complete crossing of the optic fibers. In the optic chiasm the direct fibers occupy the two lateral angles, mesial to which are the fibers coming from the nasal portion of the retina. In the center of the chiasm is the macular bundle which arises from the macula of the retina. Gudden has distinguished two types of fibers in the optic nerve, chiasm and tract, namely, those of coarse and those of fine calibre. The fine fibers in his opinion are the afferent elements which terminate in the superior colliculus, and in mammals mediate the light impulses upon which depend the pupillary reflexes. The coarse fibers, which are in the majority, convey sight impulses and are essential to visual impressions. The fine fibers undergo atrophy after destruction of the superior colliculus in young animals. This observation is of considerable clinical importance, since in a certain disease, *tabes dorsalis*, the light reflexes are abolished although vision is retained. One of the explanations offered for this phenomenon is the greater susceptibility of the fine fibers in the optic nerve to the syphilitic virus. Not all of the fibers in the optic chiasm are afferent in their course, some being efferent from the visual cortex as well as from the superior colliculus. To these fibers has been attributed the function of governing chemical changes which occur in the retina, and also movements in certain elements of the retina, the *retinal pigment cells*.

The optic chiasm, in addition to the optic nerve fibers, contains a bundle at its caudal extremity which runs along the mesial surface of the optic tracts to join the mesial geniculate body. This bundle constitutes the *inferior commissure* or *commissure of Gudden*. It bears no relation to visual function; its fibers are extremely small in diameter.

A larger collection of commissural fibers also appears in connection with the dorsal aspect of the chiasm. This commissure arises in collections of nerve cells situated on either side of the midline in the gray matter of the floor of the third ventricle immediately above the optic chiasm, constituting the *basal optic ganglia* (supra-optic nucleus). These ganglia do not appear to have any connection with the optic nerves, but the fibers derived from each ganglion immediately undergo decussation to form Meynert's commissure which is situated near the cephalic extremity of the optic chiasm. The fibers after decussation pass from the mesial side of the optic tract close to Gudden's commissure, enter the subthalamic region, and terminate in the corpus Luysi. This tract may be connected with the lenticular nucleus. On the dorsal aspect of the optic chiasm, extending out upon the dorsal surface of the optic nerve for a variable distance, from 0.5 mm. to 1 mm. in length, is a small canal which communicates with the preoptic recess of the third ventricle. This is the *supra-optic canal*.

4. THE THALAMUS. At this level elements not apparent in the more caudal sections have made their appearance. The paleothalamus consists of the *nucleus teniæ thalami*, the *nucleus medianus thalami*, and the *nucleus lateralis ventralis internus thalami*. All of these groups represent the ancient portion of the thalamus. The neothalamus is represented by the *nucleus lateralis* and the *nucleus lateralis ventralis externus*.

The nucleus teniæ thalami consists of small cells which lie in the tenia thalami cephalad of the ganglion habenulæ.

The nucleus medianus thalami is situated immediately lateral to the trigonum habenulæ and consists of medium sized stellate and fusiform cells.

The nucleus lateralis ventralis internus, also known as the nucleus ventralis, is situated ventral to the nucleus medianus thalami. It also receives fibers from the mammillo-thalamic tract. These two nuclei constituting the mesial group are separated from the lateral group by a lamina of white substance, the *lamina medullaris interna*. The internal medullary lamina is directed obliquely from above downward and bifurcates at the junction of the median and ventro-lateral internal nucleus into two divisions, one of which inserts itself between these two nuclei; the other is continuous ventrally between the two ventro-lateral nuclei. The lamina medullaris interna seems to be a projection inward of the stratum zonale which covers the dorsal surface of the thalamus. A second projection inward from the stratum zonale occupies a more lateral position and is situated between the lateral nucleus and the internal capsule. It forms the *lamina medullaris externa* which extends along the lateral aspect of the lateral and external ventro-lateral nucleus forming a boundary line between these nuclear structures and the mesial surface of the capsula interna.

5. THE SUBTHALAMUS. The subthalamic region at this level presents the several constituents already observed in the lower cross sections. Its more mesial element is an obliquely cut compact bundle of fibers making its way

from the hypothalamus toward the mesial group of nuclei in the thalamus. This is the tractus mamillo-thalamicus or the fasciculus of Vicq-d'Azyr. Mesial to this is a dense mass of fibers in the position formerly occupied by the head of the red nucleus. This is the tegmental field of Forel which, in all probability, represents the cephalic portion of the capsule surrounding the red nucleus. This tegmental area of Forel passes laterally into two zones of white matter. The more dorsal strand, which passes out laterally from the tegmental area of Forel, is the *pars dorsalis areae tegmenti of Forel*, or *tegmental field I of Forel*. The more ventral strand is the *pars ventralis areae tegmenti of Forel* or *tegmental field II of Forel*.

Ventral to the tegmental area of Forel and dorsal to the fibers of the basis is the corpus subthalamicum, now having assumed its greatest proportions.

6. BASIS DIENCEPHALI. A marked change has occurred in the disposition of the basis of the interbrain. The process in evidence in the lower sections has now been carried almost to its final stage. The fibers of this massive group of fasciculi, instead of lying transversely, are now oblique and approximate a vertical position. In consequence, they hold a lateral rather than a ventral relation to the tegmental structures. Mesial to the internal extremity of the basis encephali, is a compact circular bundle of fibers. This is formed by the *anterior pillars of the fornix*, ventro-mesial to which is a fairly large collection of small nerve cells, the *ganglion supra-optica*, from which the fibers forming the commissure of Meynert arise. The fibers of the basis diencephali in this new position have already established relations characteristic of the internal capsule. Lateral to the fibers of this capsule are the two divisions of the lenticular nucleus, the more mesial being the *globus pallidus*, the more lateral the *putamen*. In this level the internal capsule is bounded mesially by the thalamus, the tail of the caudate nucleus, and the subthalamus. Its lateral boundary consists of the *globus pallidus* of the lenticular nucleus.

Section at the Level of the Ansa Lenticularis. 1. THE CENTRAL GRAY MATTER. The central gray matter is surrounded by slightly differentiated elements and covered by the ependymal lining of the third ventricle. The ventricle is divided into a dorsal and a ventral compartment by the middle commissure.

2. THE EPITHALAMUS. At this level the roof consists of the *membrana tectoria* thrown into its typical reduplications in the formation of the *tela chorioidea superior*.

3. THE HYPOTHALAMUS. This is no longer present. The preoptic recess of the third ventricle in front of the optic chiasm constituting the preoptic recess is a subdivision of the *aula*.

4. THE THALAMUS. This consists of two main nuclei, the nucleus medialis immediately adjacent to the ventricle, and the nucleus lateralis bordering upon the internal capsule. These two nuclei are separated by the *lamina medullaris interna*, while the nucleus lateralis is demarcated from the internal capsule by the *lamina medullaris externa*. The *stratum zonale* extends over the dorsal surface of the thalamus.



Fig. 432.—Cross section through the interbrain at the level of the ansa lenticularis.

5. THE SUBTHALAMUS. At this level the most mesial element in the subthalamus is the tractus mammillo-thalamicus (fasciculus Vicq-d'Azyr) which is about to make its way into the mesial nucleus of the thalamus. The tegmental area of Forel has become much attenuated, although the two fields still bound the zona incerta. The corpus subthalamicum has disappeared.

6. THE BASIS DIENCEPHALI. The constituents which represented the basis diencephali now occupy their ultimate positions and form the internal capsule which is bounded mesially by the thalamus, subthalamus and caudate nucleus; laterally by the lenticular nucleus. Parts of the end-brain have made their appearance immediately ventral to the fibers constituting the internal capsule. These are the ansa lenticularis, anterior perforated space, and the head of the caudate nucleus. Mesial to the internal extremity of the internal capsule is the dense bundle of the anterior pillars of the fornix. The ansa lenticularis, together with other groups of arciform fibers, sweep forward and inward beneath the lenticular nucleus. This arching bundle is the *ansa peduncularis*, which consists of the following fasciculi:

(a) The deepest layer of the ansa peduncularis is subjacent to the fibers of the internal capsule and in relation with the lenticular nucleus. It constitutes the ansa lenticularis and is formed by the fasciculus of fibers which arise in the internal and external medullary lamina of the lenticular nucleus. It is probable that most of the fibers constituting this fasciculus arise in the globus pallidus.

(b) The second layer of fibers in the ansa peduncularis appears to take origin in the anterior perforated space and terminate in the mesial nucleus of the thalamus.

(c) The third layer of the ansa peduncularis is the most superficial and has been accredited with an origin principally in the Sylvian region. Its axones appear to terminate in the mesial nucleus of the thalamus, the more superficial fibers passing above the anterior pillars of the fornix and mesial to the fasciculus of Vicq-d'Azyr.

The fibers of the ansa lenticularis end in part in the corpus subthalamicum and in the cephalic extremity of the red nucleus, thus constituting a tractus lenticulo-subthalamicus and a tractus lenticulo-rubralis.

Section at the Level of the Anterior Commissure. 1. THE CENTRAL GRAY MATTER. This shows little differentiation as it surrounds the telencephalic portion of the third ventricle.

2. THE EPITHALAMUS. This consists, as in other sections, of the membrana tectoria, which forms part of the superior tela chorioidea.

3. THE THALAMUS. This consists of a nucleus medialis to which an accessory portion has been added in the more dorsal part of the nucleus dorsalis medialis, which together with the medial nucleus forms the anterior tubercle of the thalamus. Trabeculae from the lamina medullaris interna separate the nucleus dorsalis medialis from the nucleus medialis. The lower portion of the thalamus at this level is represented by the nucleus lateralis. The lateral nucleus is separated from the internal capsule by the stria lamina

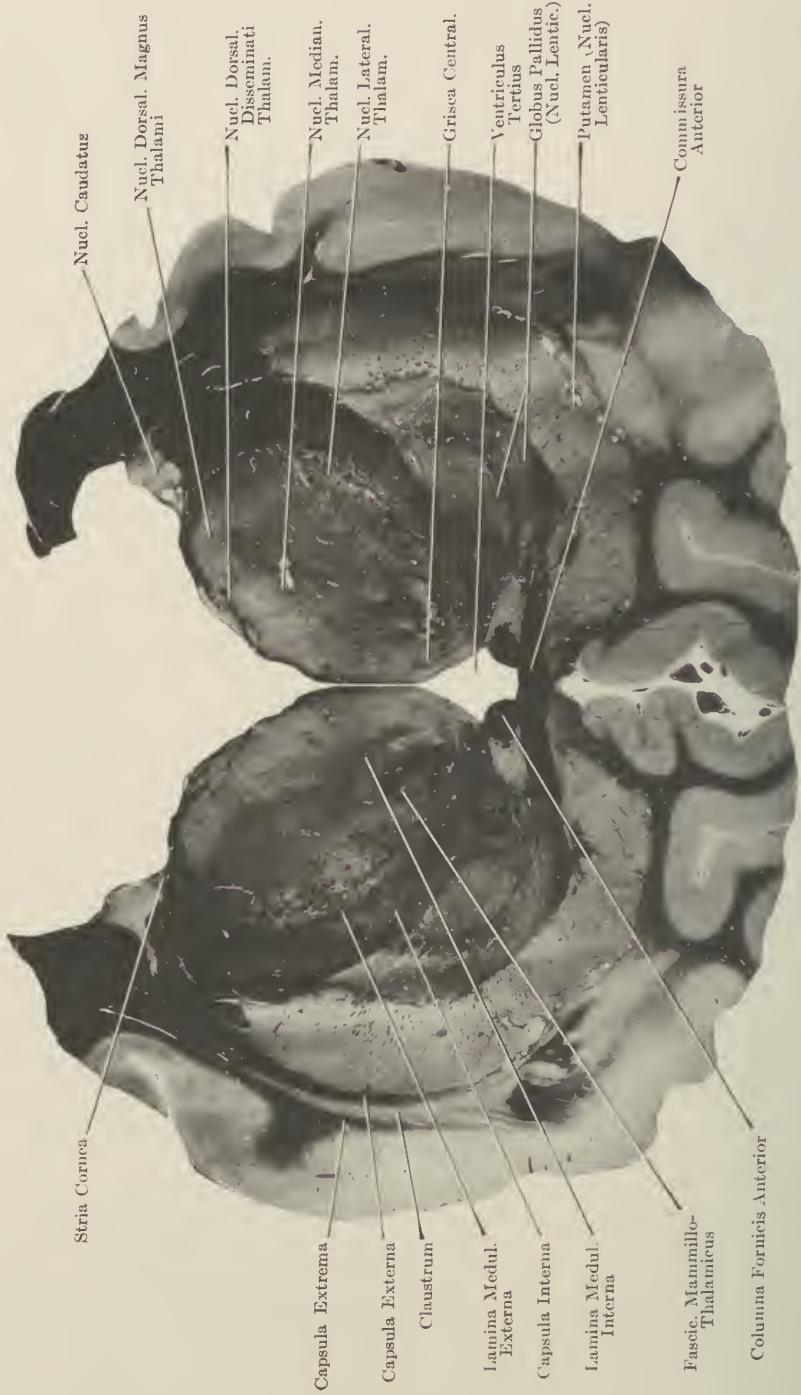


FIG. 433.—Cross section through the interbrain at the level of the anterior commissure.

medullaris externa. The mammillo-thalamic tract (fasciculus of Vicq-d'Azyr) has already terminated in the anterior nucleus.

5. THE SUBTHALAMUS. At this level it has disappeared and only some fibers of the lower stratum in the ansa lenticularis are apparent sweeping around the mesial extremity of the internal capsule to enter the mesial nucleus of the thalamus. Mesial to the internal extremity of the internal capsule the two bundles forming the anterior pillars of the fornix constitute two symmetrical circular bundles, one on either side of the midline. Ventral to the anterior pillars of the fornix is a group of crossing fibers constituting the anterior commissure, one of the oldest commissures in the endbrain. This commissure serves to connect one olfactory lobe with the other. A temporal portion of this commissure passes horizontally beneath the lenticular nucleus as far as the mesial border of the putamen, and serves to connect one temporal lobe with the other. This connection is recent, while the olfactory commissural connections are archeal.

Principal Nuclei of the Diencephalon and Their Significance. 1. NUCLEI OF THE HYPOTHALAMUS. *Mammillary Nuclei* (mesial and lateral). These nuclei establish connection between the olfactory lobe and the thalamus, and the olfactory lobe and the midbrain.

Nuclei of the Tuber Cinereum (principal, dorsal and caudal). These nuclei are probably connected with the gustatory sense and establish connection with the thalamus. They are greatly reduced in importance as compared with the homologous parts in the lower vertebrates, due to the reduction in importance of the sense of taste in man.

Supra-Optic Ganglia. The significance of these nuclei is not known.

2. NUCLEI OF THE THALAMUS. *Lateral Group, Neothalamus.* The *pulvinar and lateral geniculate bodies* represent relay stations in the projection pathway for sight impulses.

The *medial geniculate body* represents a relay nucleus in the auditory pathway.

The principal sensory nucleus or lateral nucleus of Cajal with its accessory nucleus, the external ventro-lateral nucleus, and the arcuate nucleus constitute the chief thalamic relays of the mesial fillet and the spino-thalamic tract.

The Mesial Group, Paleothalamus. The *ganglion habenulæ* and the *nucleus teniæ thalami* serve as relay stations in the efferent pathway which connects the olfactory lobe with the tegmentum of the midbrain, and thus with the nuclei of the cranial nerves and probably the cells of the ventral column of the spinal cord. They may in this manner activate movements necessary for the selection and procuring of food.

The *nucleus medialis*, *nucleus ventralis internus* and *nucleus dorsalis* represent the primitive connections of the thalamus and seem to be principally concerned with the correlation of olfactory and gustatory sensations.

To this group should be added certain nuclei of the middle commissure enumerated by Cajal as the superior internal, superior middle, and superior

commissural nuclei, the interdorsal commissural nucleus, and the oval and angular nuclei. The significance of these commissural nuclei is not clear.

3. NUCLEI OF THE SUBTHALAMUS. (a) *Nucleus of the Corpus Subthalamicum*. This collection of nerve cells represents a motor coordinating center receiving fibers from the dorsal part of the thalamus, and from the corpus striatum. Some collaterals from the pyramidal tract are said to end in this nucleus. It is probable that the body of Luys is intimately related with the corpus striatum.

(b) Diffuse nuclear groups in the zona incerta whose functions are not clearly understood.

(c) The *red nucleus* and the *substantia nigra*.

Connections of the Diencephalon and Their Significance. THE DIENCEPHALON AS A RELAY IN THE SOMATIC AND SPLANCHNIC SENSORY PATHWAYS. The neothalamus is a relay station in all of the somatic sensory pathways with the exception of the olfactory pathway, while the paleothalamus serves in the capacity of a relay station for the olfactory and gustatory sensibility. The pathways of somesthetic and special sensibility end in the several nuclei of the neothalamus. These pathways include: (a) The mesial or bulbar fillet serving for discriminative sensibility; (b) the spinal fillet (spino-thalamic tract) serving for pain-temperature sensibility; (c) the trigeminal fillet serving for general sensibility of the anterior portion of the head and face as well as the cavities of the head; (d) the lateral or pontile fillet serving for the conveyance of auditory impressions; (e) the optic fillet serving for the conveyance of visual impressions.

In the older portion of the thalamus the dorsal nucleus receives fibers from the fasciculus of Vicq-d'Azyr, which is a continuation of the anterior pillars of the fornix, while the teniæ thalami establish connections with the ganglion habenulæ. This ganglion, by the fasciculus retroflexus of Meynert, connects with the interpeduncular ganglion of Ganser and eventually with the dorsal tegmental nuclei of Gudden, which establishes a connection between the olfactory lobe on the one hand and the nuclei of the cranial nerves and possibly the ventral gray column of the spinal cord on the other. This portion of the thalamus also receives a hypothalamo-thalamic tract which serves as a relay in the gustatory pathway.

THE THALAMO-TELENCEPHALIC CONNECTION. The thalamus establishes the connections of all the great sensory pathways, except those of taste and smell, with their appropriate areas in the cerebral cortex for their final elaboration in consciousness. It is also connected with the corpus striatum. The connections of the thalamus consist of two systems of fibers:

1. The *thalamo-cortical system*, comprising the thalamic radiation in which four thalamic peduncles are recognized; namely:

(a) The anterior thalamic peduncle leaves the optic thalamus at the level of its anterior extremity. It proceeds obliquely forward, passing in the anterior segment of the internal capsule.

(b) The superior thalamic peduncle consists of thalamo-cortical fibers which enter and end in the postcentral convolution of the parietal lobe.

These fibers establish a connection between the thalamus and the cortex, serving as the final link in the somesthetic pathway.

(c) The posterior thalamic peduncle takes its origin from the pulvinar and the lateral geniculate body. It represents the optic radiation of Gratiolet. It proceeds obliquely through the retrolenticular portion of the internal capsule and terminates in the mesial surface of the occipital lobe.

(d) The inferior thalamic peduncle arises from the lateral and ventral surfaces of the thalamus, proceeds obliquely downward along the ventral surface of the lenticular nucleus, and connects with the convolutions of the temporal lobe and the island of Reil. This peduncle contributes to the formation of the ansa peduncularis which contains fibers connecting the thalamus with the corpus striatum.

The fibers in all four peduncles of the thalamus extend in both directions, those which are thalamo-cortical permitting the passage of the impulses to their final destinations in the cortex, and those which are cortico-thalamic serving to bring cortical influences to bear upon the primitive activities of the thalamus.

2. The *thalamo-striate system* represents thalamo-telencephalic connections between the thalamus and the corpus striatum. These thalamo-striate fibers present themselves as a large group of axones which enter the lenticular nucleus by passing through the internal capsule, and a second group which is more voluminous and passes beneath the ventral surface of the lenticular nucleus, where it terminates. These fasciculi form a part of the ansa peduncularis. The thalamo-striate connection is of great importance in the organization of certain reflex automatic movements which receive their sensory initiative from the thalamus and have their motor representation in the corpus striatum. Their importance will be discussed subsequently in connection with the striate body.

SUBTHALAMIC CONNECTIONS. By means of the subthalamus, the cerebellum is brought into relation with the thalamus through a relay in the red nucleus. This establishes the cerebello-rubro-thalamic connection. In all probability, this pathway is continued to the cortex by a thalamo-cortical connection. Investigation to establish this connection is still required. Clinically, it seems probable that such communication does exist, particularly for that part of the cerebellar mechanism which has to do with spatial orientation. The subthalamus also forms an intermediary in an efferent pathway from the corpus striatum, since the ansa lenticularis in part, at least, ends in the red nucleus. It is probable that in addition to its important olfactory connections by way of the mammillary bodies, the hypothalamus also serves in the capacity of a relay station for general splanchnic sensibility.

Decussations in the Diencephalon. The optic decussation, commissure or chiasm is the only important decussation in the interbrain. This corresponds in all anatomical particulars to the decussation in the several other fillets of the central nervous system already mentioned. In man it serves as a partial decussation of the sight and light fibers.

Commissures of the Diencephalon. 1. The *posterior commissure* is the caudalmost element in the epithalamus. It provides for the crossing of fibers derived from various sources. Some of its fibers probably arise in the nucleus of the posterior commissure and in the nucleus of the fasciculus longitudinalis posterior. A number of its fibers arise from the posterior portion of the thalamus of the opposite side, and some fibers crossing in it join the fasciculus retroflexus of Meynert.

2. The *supramammillary commissure of Forel*, situated above the mammillary bodies, serves these structures in a commissural capacity.

3. The *two supra-optic commissures* situated above the optic chiasm, the more cephalic of which is known as the commissure of Meynert and the caudal one as the commissure of Gudden, are little understood, and their functional significance therefore may not be given with any degree of certainty.

CHAPTER XXXIV

THE INTERBRAIN

THE FUNCTIONS AND PRINCIPAL SYNDROMES OF THE DIENCEPHALON

Three groups of facts are significant in considering the functions of the diencephalon; first, its histological characters; second, its connections; and third, its primitive vertebrate conditions.

The histological fact of chief importance concerning the interbrain is that it contains no cellular elements representative of motor specialization. The cells constituting the diencephalic nuclei are relatively small or of medium size, but are not in any particular characteristic of motor elements. This is true not only of the nuclei in the old thalamus, but in the new thalamus as well. The subthalamus presents a possible exception to this rule in that the corpus subthalamicum may have an indirect relation to motor control.

In the matter of its connections, the thalamus appears to be an internode or way station in the course of all of the great sensory pathways. It serves as an entrance for the sensory impulses from the somesthetic receptors into the domain of the cerebral hemispheres. In this sense it is the vestibule of body sensibility. Another fact concerning the connections of the diencephalon is equally important, namely, the absence of any known efferent tract connecting the thalamus directly with the final common pathway. The lack of such efferent connection itself is sufficient to call in question any possible motor functions of the diencephalon. Certainly if the organ were possessed of any degree of motor control, some connection between it and the final common pathway would be discoverable. This question has been the subject of much research, none more thorough than that of Ernest Sachs in which the Horsley-Clark stereotaxic instrument was employed for creating lesions in the brain. As a result of his extensive studies Sachs was unable to find trace of any descending connection between the spinal cord, medulla or pons and any of the nuclei of the thalamus or subthalamus.

The primitive vertebrate conditions of the diencephalon indicate that this has always been a region for the correlation of sensory impulses. The interbrain provided for the sensory combinations necessary to the formation of feeling tone in the animal and thus essential to the affective reactions. All of these facts point to the sensory nature of the thalamus.

Functions of the Thalamus and Metathalamus. The thalamus and metathalamus form a relay station for all of the sensory pathways coming from the receptors of the body.

The lateral geniculate body and the pulvinar are relays in the visual path.

The mesial geniculate body is a relay in the auditory path.

The lateral nucleus with its accessory neothalamic nuclei are relays in the somesthetic pathway.

The ganglia of the paleothalamus and the trigonum habenulæ are relays in the olfactory path. In this instance, however, the relay is in the efferent pathway.

It is probable that some of the nuclei of the mesial thalamic group serve as relays for gustatory and general splanchnic sensibility.

Stimulated from so many peripheral sources of nervous energy, the diencephalon is most advantageously placed to act as a synthetizing organ for the sensory combinations necessary to the production of the feeling tone. The interbrain has not lost this significance during the process of evolution, and still retains in man its essential relation to the affective life and emotions.

In spite of this evidence concerning the exclusively sensory nature of the thalamus, many investigators maintain that the organ is vested with motor functions. It is of interest, however, not only to note the type of motor disturbances which they attribute to it, but also to recognize the difficulties of experimentation in an area so circumscribed and adjacent to so many other important parts of the brain.

Early observers believed that the thalamus had motor functions (Magendie and Flourens), and motor responses are reported as the result of various types of experimental stimulation of the interbrain. Among these motor phenomena are included galloping movements (Magendie), movements producing running in a circle (Flourens), facial spasms, cries, howling, barking, movements of the ear, movements of the tail, movements of the body and limbs, respiratory changes and emotional expressions (Bechterew), nystagmus, nystagmoid movements, trunkal, head and limb movements (Ziehen), ear movements, frowning, tonic movements of the limbs, expressions of anger, and other affective reactions (Prus), conjugate deviation of the eyes, progression movements of the limbs, facial and mastication movements (Sachs).

This extensive list of complex somatic movements appears to be impressive evidence favoring the motor function of the interbrain. Yet all of the movements thus attributed to the thalamus may be but parts of a composite expression of emotional reactions. It is, perhaps, difficult to account for the galloping movements, the movements producing running in a circle and the progression movements of the limbs; but even these may participate in the expression of the emotion of fear giving rise to the instinctive reaction of flight or escape. It is doubtful, therefore, whether any of these movements are essentially motor functions of the thalamus; they probably represent the transmission of sensory syntheses taking place in the thalamus and serving as the incentives of motor reactions controlled by neighboring motor organs.

Clinical evidence seems to be insistent that the thalamus is a center for affective tone. Its irritation or destruction leads to changes in affective expressions and attitudes. The thalamus is a part which when diseased

may lead to forced laughing and crying (Nothnagel, Strümpell, Monokow and Gowers). It is a primary center for mimic movements and emotional expression. Irritation of it causes automatic screaming and crying, athetosis, chorea and tremor (Bechterew and Déjerine).

Psychic processes representing a certain degree of consciousness may be carried on by the thalamus independent of the cerebral cortex. These processes are probably limited to painful sensations. The thalamic centers are chiefly concerned with affective experience. Destructive lesions which involve the cortex alone do not necessarily disturb the painful and affective qualities of sensibility (Head and Holmes).

The connections of the cerebral cortex with the thalamus by means of its peduncles are important elements in the thalamic functions. The superior and posterior peduncles of the thalamus form the final links in the pathways of somesthetic and visual sensibility, conveying impulses received by the receptors of these two types of sense to their ultimate cortical areas. In these areas they attain their fullest significance in consciousness. The inferior peduncle of the thalamus is the last connecting link in the auditory sense, and conveys impulses of hearing to the temporal cortex, where they become properly associated and memorized.

The anterior peduncle of the thalamus has a different destination and, apparently, a different purpose. It terminates in the frontal lobe of the brain to which no special sense is attributed. This lobe is regarded as the seat of the higher intellectual faculties and of those composites of experience which constitute personality. The frontal lobe has the dominant control of all behavioral reactions. Its thalamic connection provides for a great expansion of feeling tone and permits the thalamus to furnish the primitive affective incentives which play such a compelling part in the motives of all voluntary activity.

Personality and behavior in their most complex form still retain their basic relations to the primitive emotions. The archeal current of feeling tone arising from the interbrain pervades all of the higher psychic faculties and colors them with some degree of pleasure or displeasure. The primitive emotion of fear which is indispensable to the preservation of life may become greatly expanded. Combined with other memory associations which have entered into experience, fear may give rise to the many behavioral reactions of caution necessary to escape or avoid the dangers and embarrassments of life. The primitive emotions of anger and positive self-regarding feeling underlying the fundamental instinctive reaction of attack or aggression may likewise be so combined in experience as to become the incentive for those complex behavioral acts necessary to make and maintain a place in the social organization. The primitive emotion of parental feeling, probably arising first in the thalamus, is capable of great expansion in its psychic combinations within the cerebral cortex, where it develops into the sentiment of sympathy and fraternal feeling. In this manner the simple elements of feeling tone are capable of entering into secondary and tertiary combinations and thus determine the more complex emotions and sentiments. Yet,

however complex they may become, these psychic combinations of the cerebral cortex are fundamentally dependent upon the thalamus for their primitive source of affective energy.

The far-reaching influence of this expansion in consciousness of the primitive emotions cannot be overestimated as a factor in the development of human behavior and of human society. These possibilities of expansion, however, are not without their disadvantages and dangers. The emotion of fear, the sexual emotion, as well as other primitive emotions, may become pathologically expanded and result in such marked deviations in their corresponding reactions as to cause the symptoms of recognizable disease. A pathological expansion of this kind underlies the production of that extensive group of nervous maladies known as the neuroses and the psychoses.

Fibers in the peduncles of the thalamus arise in the cortex and end in the thalamic nuclei. These cortico-thalamic connections in all probability supply a cortical control to the thalamus. This control in turn subjects the source of affective energy to supervision by the higher psychic processes. When this connection is interrupted by disease or injury, affective expression, being deprived of its natural inhibitory regulation, has a freer play and presents itself in recognizable symptoms, such as paroxysmal attacks of laughing and crying.

The numerous connections which the thalamus maintains with the corpus striatum, and in particular with the lenticular nucleus, serve the purpose of transmitting to this part of the endbrain correlated sensory impulses synthesized in the thalamus. This relation to the corpus striatum will be discussed subsequently in the chapter dealing with that part of the brain.

Functions of the Subthalamus. The subthalamus, and in particular the corpus subthalamicum, is concerned with motor correlations connected with the corpus striatum, the significance of which will be subsequently discussed.

Functions of the Epithalamus. The functions of the epithalamus in man are attributable to its major structures—the pineal gland and the tela chorioidea superior or chorioidal gland. That the pineal gland is a glandular structure is a much debated question. Recent clinical and pathological investigations, however, seem to point to the conclusion that the pineal gland is to be included among the other endocrinic organs of the body. Primary disease in it results in manifest disturbances of metabolism. The removal of it likewise causes marked changes, especially in the rate of skeletal growth and the differentiation of the sexual organs. Histological evidence associates this structure with the endocrinic system, and justifies the conclusion that the epiphysis cerebri in man and mammals is a gland of internal secretion which contributes its secretory product directly to the blood stream. The effect of this secretion upon the organism is in the interest of regulating somatic growth and sexual differentiation. The secretion of the pineal gland appears to influence skeletal development in such a way as to retard its excessive and premature growth during the first and second decades

of life. Its functional activity declines in later years. The gland seems to have the same retarding influence upon the premature differentiation of the primary and secondary sex characters. It inhibits the maturity of growth and sex differentiation by holding in check any possible precocity in these important phases of ontogenesis.

The tela chorioidea superior or chorioid gland secretes the cerebrospinal fluid and contributes in all probability a nutritive material essential to the central nervous system. The function of the cerebrospinal fluid as an outer investment for the spinal cord and, to a less degree, for the brain, is a secondary office of this fluid.

Functions of the Hypothalamus. The mammillary body serves as a relay station in the olfactory tract, especially participating in the conduction of efferent impulses conveyed inward from the olfactory lobe. Through the intervention of the tegmentum of the midbrain, these impulses are directed to the cranial nerve nuclei and possibly to the cells in the ventral gray column of the cord in order to influence motor activities. The importance of the mammillary body in man is much reduced as compared with the lower vertebrates.

The tuber cinereum serves as a relay station in the gustatory tract. Its relations in this connection are too little understood to justify explicit statements concerning their actual nature.

The hypophysis cerebri, through the activities of the pituitary gland, acts as a part of the endocrinic system of the body. It is a gland of internal secretion contributing its secretory product directly to the blood stream. It exerts a decided influence upon somatic growth and also upon sexual differentiation. Its secretion serves to accelerate osseous development and the differentiation of the primary and secondary sex characters. Defects in its secretion cause retardation of sexual differentiation and may result in the retardation of osseous growth. According to the most reliable evidence, the secretion of this gland has a material effect upon carbohydrate metabolism. It appears to mobilize the glycogen of the liver, and also has some influence upon the mobilization and conversion of fats.

PRINCIPAL SYNDROMES OF THE DIENCEPHALON

Syndrome of the Thalamus. HISTORY. The patient, a Russian, aged thirty-six years, complained of suffering from a loss of sensation of the right half of the body, accompanied by paroxysmal pain in this region with a peculiar twitching and tremor of the right arm and leg and irregular twisting movements of these parts. From time to time he was subject to unprovoked outbursts of laughing and weeping, although he felt no corresponding emotion on such occasions. This trouble had its beginning two years before the examination when, after an oppressively hot day, the patient retired and fell asleep. He was aroused by a disturbing dream toward morning. Out of this dream he was partially awakened in fear, for he had dreamed that outside of his window the Germans and the Russians were waging a hand-to-

hand combat. The Russians were being overcome. All of this transpired during the progress of the Great War, the events of which were fresh in the patient's mind. Upon seeing the misfortune of his countrymen he determined to go to their aid and became intensely wrought up in attempting to do so. Being half awake he made a violent effort to shout and spring from bed, but in the attempt he fell, paralyzed on his right side, and lost the power of speech. He soon lost consciousness and was taken to the hospital. During his residence in the hospital he regained the power of speech, and the paralysis of the right side disappeared in two months. Paroxysms of pain

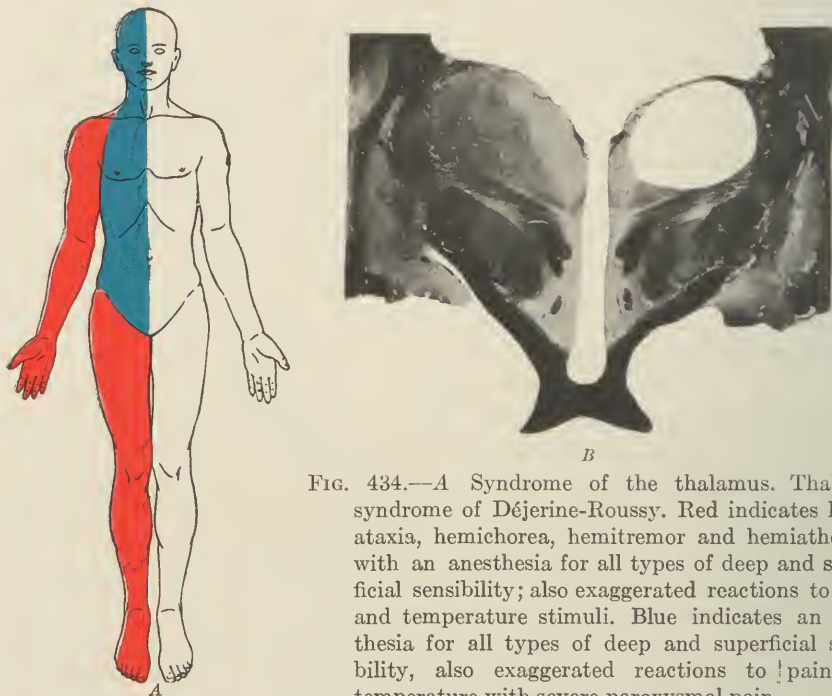


FIG. 434.—A Syndrome of the thalamus. Thalamic syndrome of Déjerine-Roussy. Red indicates hemiataxia, hemichorea, hemitremor and hemiathetosis with an anesthesia for all types of deep and superficial sensibility; also exaggerated reactions to pain and temperature stimuli. Blue indicates an anesthesia for all types of deep and superficial sensibility, also exaggerated reactions to pain and temperature with severe paroxysmal pain.

B. Cross section through the interbrain showing the location of the lesion in the thalamic syndrome of Déjerine-Roussy: Involvement of the median and lateral nuclei of the optic thalamus.

in his right arm and shoulder, in the right side of his body, and in the right leg finally made their appearance, as did also certain peculiar involuntary movements in the right arm and leg. His emotional outbursts developed two months later, at about which time he became conscious of a marked loss of sensation in the entire right half of the body.

His family history showed no ancestral taint.

His personal history was negative with reference to excesses of any kind. There was no history of syphilis; his wife had had no miscarriages.

EXAMINATION. Upon examination two years after the onset of his disease the following observations were made:

The Somatic Motor Component. Idiodynamic, reflex and tonic control of the entire body musculature was normal. There was no paralysis upon either side; there was no loss or increase of tone. The reflexes were normal and equal on both sides. No pathological reflex was present in either upper or lower extremities. Volitional control was normal so far as the initiation of all movements was concerned, but was much disturbed by the presence of irregular involuntary movements which consisted in part of a tremor, in part of an irregular twisting motion with a constant opening and closing of the fingers of the right hand. There were also twitchings of the arm and forearm, of the head and face upon the right side. These irregular involuntary movements became greatly increased when the patient was agitated or when his attention was directed to his trouble. His speech showed the defects of these irregular involuntary movements, which were classified as choreo-athetosis. The tremor belonged to the asynergic group, being irregular in its force and amplitude. The synergic control of the muscles was at fault, and the patient in the performance of any skilled act with the right arm or leg showed a marked dysmetria, together with constant ataxia. The automatic associated control was normal and there were no abnormal associated movements on either side.

All of the cranial nerves were normal.

The somatic sensory component. This component showed the following pronounced disorders: Subjectively, the patient complained of severe paroxysmal pains coming on spontaneously and without warning either in the arm or leg. Their most frequent location was in the shoulder. They were extremely severe and often caused the patient to cry out. They disappeared as suddenly as they came and left the patient in a state of exhaustion. They were confined exclusively to the right side of the body.

Objectively, it was found that the patient had a peculiar disturbance of tactile sensibility in that he could not recognize the point of a pin when placed upon any part of the right side of his body up to the midsagittal line. If the point of the pin were drawn even gently across the skin of any part of the right side, he experienced a most disagreeable and painful sensation. Tactile stimuli on the right side produced no proper perception. On the left side all sensation was normal. Pain and temperature sensibility were much reduced upon the right side of the body up to the midline. This was true also of muscle, joint and vibratory sensibility. Objects of different size and shape with which the patient was formerly familiar, if placed in his right hand, could not be identified by palpation alone, but if placed in the left hand were immediately identified. Objects of different surfaces and texture placed upon the sole of the foot or rubbed along the skin of the sole were not recognized on the right side, but identified at once on the left.

He was suffering from a pronounced right hemianesthesia, loss of body sensibility, with a peculiar affect modification arising from stimuli on the right half of the body. In addition he had a right astereognosis (the inability to recognize the form of objects by palpation). Combined with these symptoms there was the marked spontaneous pain in the right side of the body.

The Splanchnic Motor Component. This component was normal.

The Splanchnic Sensory Component. This component so far as could be judged from the history and examination of the patient showed no deviation from the normal.

The mental status was normal in all respects, except for the excessive imbalance in the emotional state, as witnessed by the unprovoked outbursts of laughter and crying.

The blood and spinal fluid Wassermann reactions were negative.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was considered to be vascular because of its sudden onset and its tendency toward improvement.

Evidence of the focus of the lesion is afforded by the emotional instability, the loss of sensation on one half of the body, the peculiar affective change in the anesthetic side, the spontaneous pain in the right side, and the choreo-athetoid movements with the tremor confined to the right side of the body. All of these symptoms may be accounted for by a lesion in the left thalamus in which are relayed the fibers of the mesial and spinal fillets. The emotional disturbance is explained by irritation of the thalamus. The choreo-athetosis and tremor are due, in all probability, to the extension of the lesion to the subthalamus, where it involved the cephalic extremity of the red nucleus and the corpus subthalamicum.

Evidence of the circumscription of the lesion is afforded by the absence of any other somatic motor disturbance, the absence of paralysis, the absence of changes in the deep and superficial reflexes, as well as the absence of disturbances in idiodynamic and tonic control of the muscles. The restriction of the symptoms to the right side of the body indicates a lesion in the left thalamus.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is a vascular lesion, probably a small hemorrhage in the left thalamus.

NOMENCLATURE. This is known as the *thalamic syndrome* or the *syndrome of Déjerine-Roussy*.

VARIATIONS. The thalamic syndrome is frequently complicated by the presence of an homonymous hemianopsia; that is, a loss of vision in the corresponding half of each eye, so that the patient is blind on looking either to the right or to the left, but retains vision in the opposite direction. This is due to the extension of the lesion to the pulvinar and lateral geniculate body which interrupts the sight fibers as they are entering or leaving these relays in the visual pathway.

SUMMARY. The essential clinical features of the thalamic syndrome are:

1. A hemianesthesia contralateral to the lesion more or less marked for all types of deep and superficial sensibility, including tactile, muscle-joint, vibratory, pain and temperature senses.
2. Exaggerated reactions to painful and thermic stimuli out of proportion to the intensity of the stimulation upon the hemianesthetic area.
3. A complete astereognosis upon the anesthetic side of the body.
4. Some degree of hemiataxia, hemitremor, hemichorea and hemiathe-tosis upon the anesthetic side.

5. Severe paroxysmal pain upon the anesthetic side. These are lancinating paroxysms which resist all analgesic medications.

6. Marked emotional disturbances as manifested in unprovoked outbursts of weeping and laughing.

7. The absence of all other somatic and sensory disturbances as well as all splanchnic motor or sensory disturbances.

The Syndrome of the Subthalamus. **HISTORY.** The patient, a boy, eight years of age, gave a history of a progressive disturbance of the right arm and leg in which the muscles of these parts caused the limb to twitch as in St. Vitus' dance. In fact, this diagnosis was made in the early part of his sickness, which lasted for eight months. After several months of this trouble, which was unyielding to treatment, the parents noticed that the boy had lost the power to move the eyes upward or downward on attempting to look in these directions. After three months it was noticed that he did not use the right arm and leg as well as formerly. He stumbled and fell toward the right side and his movements with the right arm were not only disturbed by the peculiar choreiform twitchings, but were also very irregular in their execution. He complained of no pain or other disturbance. His appetite was good; he had a slight intermittent fever throughout the course of his trouble. At the end of five months he began to manifest a new symptom; that is, sudden outbursts of prolonged screaming and crying without any provocation, continuing unabated in spite of all admonitions. These attacks would leave him in a prostrated condition. Two months later the right arm and leg, while presenting a mild degree of peculiar twitching movements, seemed to be completely paralyzed. At the end of eight months the child suddenly died. During the course of his disease, the von Pirquet test was taken several times and found on each occasion to be strongly positive. One younger sister had died of a tuberculous meningitis. The father and mother were healthy although there was a history of tuberculosis in the family.

EXAMINATION. Upon examination two months before death the following observations were made:

The Somatic Motor Component. This component showed that the idiodynamic control of the entire musculature of the body was normal.

The tonic control showed a marked increase in the tone of the muscles in the right arm and leg and the right side of the neck. The deep reflexes on the right side of the body were all more active than those on the left. There was a right ankle clonus and a right Babinski, but no pathological reflexes were observed on the left side. The right superficial reflexes, including the cremasteric, the upper and lower lateral abdominals, were all absent. They were present and active upon the left side. Volitional control showed a marked loss of strength and regulation in the right arm and leg. The patient had considerable difficulty in speaking toward the end of the disease. Synergic control was distinctly defective, as shown partly in the hemiataxia and also in the choreiform movements with which the disease began and which continued until the last few months of the child's life. Abnormal

involuntary movements other than those described were not present. Abnormal associated movements were developed in both upper and lower extremities on the right side under the appropriate tests, thus indicating a pyramidal tract involvement. All of the cranial nerves were normal with the exception of the oculomotor nerves; there was no change in the olfactory sense. Vision was normal; there was no choked disc or other alteration of the eye grounds. Hearing was normal on both sides, as was the sense of taste. The only defect of the cranial nerves was in the paralysis of vertical gaze, the

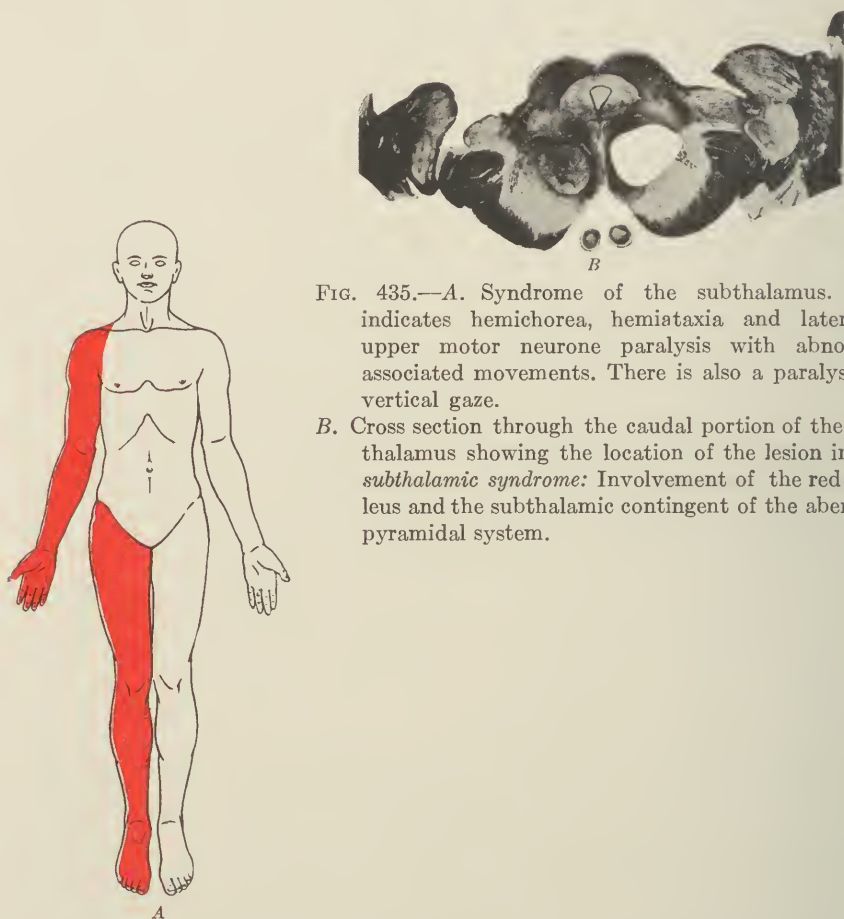


FIG. 435.—A. Syndrome of the subthalamus. Red indicates hemichorea, hemiataxia and later an upper motor neurone paralysis with abnormal associated movements. There is also a paralysis of vertical gaze.

B. Cross section through the caudal portion of the subthalamus showing the location of the lesion in the *subthalamic syndrome*: Involvement of the red nucleus and the subthalamic contingent of the aberrant pyramidal system.

patient being unable to move the eyes upward or downward, although all other ocular movements were normally performed. There was no ocular dissociation, no strabismus, no nystagmus. The fifth and seventh nerves were normal, as were also the ninth, tenth, eleventh and twelfth.

The Somatic Sensory Component. This component as a result of several examinations of all qualities of sensation, failed to reveal any disturbance of somesthetic sensibility.

The Splanchnic Motor Component. This component was normal.

The Splanchnic Sensory Component. This component showed no evidence of any pathological involvement.

The mental status was normal with the possible exception of the occasional screaming and crying spells of which the child had a number toward the end of his illness.

LABORATORY TESTS. The spinal fluid showed forty to fifty lymphocytes upon repeated counts, but no organism was isolated in the fluid. The Wassermann reaction was negative in the blood and spinal fluid. The blood was otherwise normal and the urine was negative to all tests.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was tuberculous.

Evidence of the focus of the lesion is afforded by the paralysis of vertical gaze, the hemichorea with ultimate hemiplegia. The paralysis of vertical gaze is explained by the involvement of the *subthalamic contingent of the aberrant pyramidal system* which leaves the basis diencephali immediately beneath the corpus subthalamicum and makes its way dorsad to end in the portion of the third nerve nucleus which innervates the superior and inferior recti. The hemichorea was determined by an involvement of the red nucleus the cephalic extremity of which is in relation with the subthalamic contingent of the aberrant pyramidal system, while the ultimate hemiplegia was due to the involvement of the pyramidal tract. The emotional disturbance seen in the spasmodic screaming and crying attacks which appeared late in the course of the disease was attributed to an extension of the lesion to the thalamus.

Evidence of circumscription of the lesion is afforded by the limitation of the symptoms to the right side of the body, the absence of sensory symptoms and the absence of the involvement of any other cranial nerves than that mentioned.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this case was a tuberculoma of the left subthalamus.

NOMENCLATURE. This is known as the *subthalamic syndrome*; it is also known as the *syndrome of hemiplegia with paralysis of vertical gaze*.

SUMMARY. The essential clinical features of the subthalamic syndrome are:

1. Paralysis of vertical gaze.
2. Hemichorea and hemiataxia.
3. Hemiplegia; all of these motor disturbances being upon the same side, contralateral to the lesion.
4. The absence of all sensory disturbances as well as all disturbances of the splanchnic motor and sensory systems.

Syndrome of the Hypothalamus. HISTORY. The patient, a man twenty-eight years of age, a school teacher by profession, had read much concerning his own malady and gave the following account of his disease:

"In my early boyhood the bones over my eyes began to become very prominent, and I remember being told by my mother to try to exert pressure on the bone by rubbing it with my hand; but rubbing did not stop the

growing. When I was nineteen years of age my vision became greatly impaired; I could see well enough with both eyes together or with one eye closed for objects immediately in front of me, but objects to the right or left



FIG. 436.—Patient suffering from the hypothalamic syndrome of Marie showing the marked acromegalic changes in the acral portions of the hands, feet and head. (Falla.)

were either dimly seen or not seen at all, so that I frequently while walking bumped into people either on the right side or the left. I consulted an eye specialist at this time who prescribed glasses. For a while my eyes began to improve. At this time the bones of my head, particularly those above my eyes, in my lower jaw as well as my nose, began to grow larger, so that my whole face had a most misshapen and unpleasant appearance. I also noticed that my hands and feet increased in size and where I was able to wear a number 8 shoe and glove before, it was now necessary for me to buy shoes and gloves three or four sizes larger. This increase in the size of my hands and feet seemed to be out of proportion to the growth of the rest of my bones, although my chest seemed to be expanding also. One day while attending the summer school at the University of Chicago, I was told by a medical student that I was suffering from *acromegaly*. He had made the diagnosis from my facial expression and told me that I should at once see a prominent surgeon of that city. In consequence I went to the hospital in order that tests should be made to determine my sugar tolerance. Ordinarily 50 grams of dextrose will cause sugar to appear in the urine, but upon taking 150 grams there were no signs of sugar in my

urine. About this time I had frequent headaches in the occipital region which eating would seem to relieve, and I suppose putting food in my stomach called the blood from my head and relieved the pressure. In 1914

I went to Boston to consult a noted brain surgeon, who advised an immediate operation. As I understand, he made an entrance into the head between my upper teeth and lip and behind the nose, and removed, according to reports, an enlarged pituitary body. Since the operation, now over three years ago, my general condition has been better. The headaches have more or less ceased. I think, however, that my bones in the head and in the hands and feet are still growing. Formerly only two or three teeth would occlude when I closed the lower jaw; recently the dentist made an extra upper set of teeth to fit over my normal ones; they help me greatly in chewing.

"An interesting point in connection with my case is that an uncle of my father was over seven feet tall. Gould and Pile's "Anomalies and Curiosities of Medicine" has this to say about him: 'On June 17th 1871, there were married at St. Martin's in the Field in London, Captain Martin Van Buren Bates of Kentucky and Miss Anna Swann of Nova Scotia, two celebrated exhibitionists, both of whom were over seven feet. Captain Bates is familiarly known as the Kentucky Giant and years ago was a familiar figure in many northern cities where he exhibited himself in company with his wife, the combined height of the two being greater than that of any couple known to history. Captain Bates was born in Whitesburg, Letcher County, Ky., on November 9th, 1845. He enlisted in the Southern Army in 1861 and although only sixteen years old was admitted to service because of his great size. At the close of the war Captain Bates had attained his great height of seven feet, two and a half inches. His body was well proportioned; his weight increased until he weighed 400 pounds.'

"My own height is a little over five feet and nine inches."

EXAMINATION. Upon examination of the patient the following observations were made:

The Somatic Motor Component. This component was normal in all respects. There was no change of idiodynamic, tonic, reflex, volitional, synergic and automatic associated control of any of the muscles of the body. X-ray of the skeletal system showed a marked increase of the bones of the head, feet and hands and also of the ribs. The increase in bony tissue was most marked at the acral or sharp points, as above the eyebrows, on the nose and the jaws, as well as the phalanges of the fingers and toes. The osseous change was due to a marked bony thickening of the parts mentioned. The x-ray of the skull showed that the floor of the sella turcica had been removed at the time of operation in order to permit the approach to and removal of a tumor in the pituitary fossa. All of the cranial nerves at the time of the examination were normal.

The Somatic Sensory Component. This component was normal.

The Splanchnic Motor and Sensory Components. These components were normal in all respects.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion in this case was a neoplasm.

Evidence of the focus of the lesion is afforded by the peculiar kind of blindness from which the patient suffered before the removal of the tumor. This is what is known as bitemporal hemianopsia, as a result of which vision

for objects directly in front of the patient was normal, but in the temporal fields on both sides the patient was blind. In addition to this there was the marked change in the osseous tissue of the body, especially in the head, face and extremities, and the marked tolerance for sugar. A tumor growing in the hypophysis cerebri rising out of the sella turcica and pressing forward would compromise the crossing fibers in the optic chiasm, thus producing the bitemporal hemianopsia or loss of bitemporal vision. Such a



FIG. 437.—A. X-ray of the skull of the case reported as an example of the hypothalamic syndrome of acromegaly; syndrome of Marie. The acral portions of the cranium, such as the jaw, nose and brow, show a marked increase in the bone.

B. Cross section through the interbrain showing the location of the lesion in the *hypothalamic syndrome of Marie*: Involvement of the hypophysis cerebri and optic chiasm.

tumor in the pituitary gland causing an increase in its secretion would lead to the osseous changes described, and probably explain the marked increase in sugar tolerance.

Evidence of circumscription of the lesion is afforded by the absence of all somatic motor and sensory and splanchnic motor and sensory symptoms.

DIAGNOSIS AND PATHOLOGY. The condition in this case was a tumor of the pituitary gland.

NOMENCLATURE. This is known as the *pituitary syndrome* or *acromegaly*. It is also called the *syndrome of Marie*.

VARIATIONS. Certain variations occur in this syndrome depending upon the time of life at which the changes in the pituitary gland make their appearance. If these changes occur during the time of adolescence the resulting condition is known as *gigantism*. This disturbance is undoubtedly represented by the patient's great uncle who was famed as the Kentucky Giant. Under these circumstances the condition is known as the *syndrome of gigantism* or the *syndrome of Launois*. Both the syndrome of Marie and the syndrome of Launois are due to excessive pituitary secretion. In case of a hyposecretion of the pituitary gland, due to atrophy or sclerosis, the resulting condition is characterized by the retarded differentiation of the primary and secondary sex characters and a deposition of a large amount of subcutaneous fat, especially about the hips and thighs and above the mammæ. This is known as the *syndrome of dystrophia adiposo-genitalis*. It is also known as the *syndrome of Fröhlich*. This disease occurs in adolescence; but when the pituitary gland ceases to perform its functions or when its functions are deficient after adult life has been attained, there is produced a reversion with atrophy of the primary and secondary sex characters, often with a deposit of subcutaneous fat around the hips and thighs. This is sometimes referred to as the *syndrome of Cushing*, in recognition of the researches of the American surgeon whose experimental work has demonstrated the effect of the removal of the hypophysis in adult animals.

SUMMARY. The essential clinical features in the syndrome of acromegaly are:

1. Increase of the bony tissue in the principal acral points of the body, in the head, extremities and chest.
2. Bitemporal hemianopsia.
3. Increased sugar tolerance.
4. Intermittent headaches.
5. The absence of all other somatic motor and sensory and splanchnic motor and sensory symptoms.

Syndrome of the Epithalamus. **HISTORY.** The patient, a boy eight years of age, had suffered from recurrent headaches since his sixth year. In his eighth year his headaches had become more severe and he had suffered from vomiting attacks. His vision was not so good as it had been and upon advice he began to wear glasses. During his eighth year he grew rapidly until he had reached the height of five feet three inches. He was as large as a boy of fourteen. In addition to this increase in stature, axillary and pubic hair made its appearance and reached full development. His external genitalia became as large as in the adult and his sexual functions were fully established. His voice underwent transition and became much deepened. During this time, however, he suffered from repeated headaches and his vision progressively failed. Upon examination by an oculist he was told that he had progressive optic atrophy. He was admitted to the hospital because of his severe headaches and vomiting. At this time his vision was

practically gone. Shortly after admittance to the hospital he was seized with a convulsion which lasted for half an hour. After this convulsion he never recovered consciousness but lapsed into a somnolent condition in which he remained for several weeks, at the end of which time he had a second convulsion and died two days later.

EXAMINATION. Upon examination at the time of his entrance into the hospital the following observations were made:

The Somatic Motor Component. This component showed that the idio-dynamic control of muscles was normal. All of the deep reflexes were active and equal on the two sides. There was a slight increase in muscle tone in both legs and also, to a slighter degree, in the arms. The patient gave evidence of slight loss of volitional control in both legs and arms. The automatic associated control was normal. The patient, although a child of eight years, had the appearance of a boy of fifteen or sixteen both in size and development. All the cranial nerves were normal except the second, which showed complete optic atrophy with complete bilateral blindness.

The Somatic Sensory Component. This component was normal in all qualities.

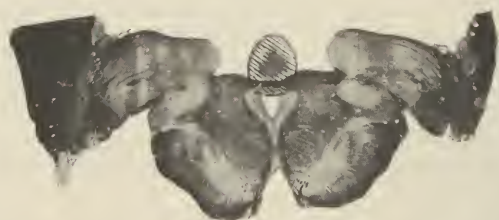


FIG. 438.—Cross section through the area of transition between midbrain and interbrain showing the location of the lesion in the *epithalamic syndrome*: Involvement of the pineal gland with secondary pressure effects upon the roof of the midbrain.

The Splanchnic Motor and Sensory Components. These components were normal.

MENTAL STATUS. The mental status of the patient in many respects was difficult to estimate. He seemed precocious in certain particulars but definitely retarded in others. He had been unable to attend school because of his headaches and for this reason his actual rating could not be made. Furthermore, on his admittance to the hospital, he was suffering from such extreme headaches that only the statement of his parents could be depended upon in estimating his mental age.

LABORATORY TESTS. The spinal fluid on lumbar puncture appeared to be under increased tension, but it was negative to all special tests. The blood and urine were also negative.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion in this case was a brain tumor.

Evidence of the focus of the lesion was afforded by the premature somatic development and precocious sexual differentiation and growth. This can be explained on the basis of a lesion destroying the pineal gland.

The optic atrophy and blindness, together with the headaches, convulsions, somnolence and death, can be accounted for by a growth involving the pineal gland in such a way as to compromise the aqueduct of Sylvius and thus give rise to an internal hydrocephalus. This explains the visual as well as all of the motor disturbances in the case.

Evidence of circumscription of the lesion is afforded by the absence of all other motor and sensory symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is tumor of the pineal body.

NOMENCLATURE. This is known as the *epiphyseal syndrome*. It is also called the *syndrome of Pellezzi* or the *syndrome of macro-genito-somia precox*.

SUMMARY. The essential clinical features of the syndrome of the epiphysis are:

1. Precocious development and differentiation of the external genitalia, the premature appearance of the axillary and pubic hair.
2. Precocious development of sexual function.
3. Precocious abnormal growth of the long bones, producing a stature of abnormal development.
4. The appearance of signs of internal hydrocephalus, including visual disorders, headache, vomiting, with choked disc or optic atrophy.
5. The absence of all other motor and sensory symptoms.

CHAPTER XXXV

THE ENDBRAIN

THE CEREBRAL HEMISPHERES

The Significance of the Endbrain—The Cerebral Hemispheres. The endbrain, which, like the cerebellum and tectum mesencephali, is a suprasegmental part of the central nervous system, constitutes the largest portion of the encephalon in man. By weight and volume it represents approximately 70 per cent. of the entire nervous system. This dominance in size of the human telencephalon is one of the features in which it differs from the endbrain of many of the lower animals. In the anthropoid apes the surface of the endbrain has a somewhat more simple pattern than in man, although it maintains approximately the same relative volume. In the lower apes the configuration of the surface is much less complex than in the anthropoids. A progressive decrease in complexity and size is observed in passing from the lower mammals to the birds, reptiles, amphibia and fish. The endbrain of the fish, in many forms, is even less prominent than other parts of the brain. The relative difference between the telencephalon of the fish and that of man indicates a developmental process with far-reaching effects, for hand in hand with the progressive evolution of the endbrain have gone the changes of a progressive behavioral adaption.

The Endbrain in Relation to Animal Behavior. As the endbrain gradually increased in size and prominence, new capacities for experience were added to the central nervous mechanism. These advances have especially made themselves felt in animal behavior, which manifests itself as a series of reactions through which nervous energy is externalized.

In its simplest forms behavior presents certain routine and inflexible limitations. Given causes determine certain invariable and constant responses, the number of which is limited. Such reactions constitute *fixed* or *rigid behavior* which is dependent upon a correspondingly limited experience. Animals exhibiting this type of behavior are able to sense their world in the most restricted manner only. Their total experience may depend solely upon tactile and visceral impressions. Without further expansion in this sensory sphere there would be little opportunity for more complex and progressive adaptations.

Experience, therefore, in order to take advantage of wider opportunities, became amplified by the addition to it of sensory impressions received from sensitized end-organs adequate to transmit such special types of stimuli as those of smell, taste, sight and hearing. It was even more effectually expanded by extensive combinations of these sensory impressions in parts of the nervous system especially provided for such syntheses. Correlations

of this kind determined associated sensory perceptions, in consequence of which the elements of the environment were more amply sensed and the corresponding behavioral responses were thus rendered more effective. Not alone was the animal, under these circumstances, capable of performing more motor acts, but through these acts it was able to effect new purposes and meet new emergencies.

Experience in this light represents the sum total of the sensory impressions received by the end-organs and correlated in the brain, while behavior is the expression of this total.

Individual and Generic Behavior. How much experience varies at different periods of life is witnessed by differences in behavior. The infant, whose sensory intake at first pertains to the splanchnic component, reacts principally in response to the feelings of hunger. The subsequent addition of visual, olfactory, gustatory and auditory impressions increases the horizon of consciousness. Much sensory accretion continues through the different stages of life with the result that experience becomes enriched by innumerable complex syntheses of sensory impressions. Indeed, these combinations acquire such complexity that no two experiences are quite alike. The experiences of the soldier, and the scholar, the explorer and the clerk, are totally different and individualistic. They, however, represent type differences only. No two soldiers or scholars are exactly similar in their individuality, for each individual becomes highly differentiated and is the embodiment of a distinctive personality. Out of such complex and individualized experience there naturally develop complex reactions, as, for example, those represented by human behavior.

Contrasted with the more fixed and rigid reactions of lower animals, these human reactions constitute an extremely flexible and plastic behavior. Here a given cause does not under all circumstances determine the same response. Among men differences in behavioral reaction are as numerous as the differences in stature and general appearance. Individualization, although in less marked degree, is also seen in all mammals, but in every instance it is an acquisition attained through individual development. It is that which the individual learns for himself by imitation and repetition through trial and error. Its expression, being conditioned by the development of the individual, may be designated *ontogenetic* or *individual behavior*.

In addition to these individualizing reactions, there is an extensive series in which all animals are much alike and manifest but little individual difference. These reactions constitute *generic behavior* in contradistinction to the more highly specialized *individual behavior*. The primitive feelings of hunger, of sexual excitement, of anger, of fear and of hate call such behavioral reactions into play. In their nature these responses are archeal, have a common mode of expression, are clearly discernible in all vertebrates, and appear to be transmitted as a heritage necessary to the maintenance and perpetuation of life. They are phylogenetically conditioned, since they represent inherent phyletic acquisitions whose history is at least as ancient as that of the vertebrates.

Of these two types of behavioral reactions, therefore, *generic behavior* appears to be the most fundamental, while *individual behavior* presents a slowly progressive evolution eventually finding its fullest expression in man.

Mechanism of the Endbrain in the Expansion of Experience. That the endbrain controls individual behavior there can be no doubt. The cerebral hemispheres have made possible the great expansion of experience underlying this type of behavioral reaction. This expansion is dependent upon two factors; first, the provision of special areas for the further elaboration of each type of sensibility; and, second, a mechanism through which the several sensory areas of the brain are brought into relation with each other. By this means all of the sensory contributions to experience are conducted into a common blending or mixing area. Here somesthetic perceptions are associated with those of vision, hearing, smell and taste in such a way that each specific sensory impulse is not only capable of expansion in its own particular sphere, but may also enter into many other associations by combining with the sensory perceptions from other sensory spheres. If, for example, the letter *T* be allowed to represent an impulse of tactile sensibility, then all that goes on in the area of the cortex designed for tactile perceptions might be represented by the mathematical expression of *T* plus *T* plus *T*, and so on. Similarly, if *V* represents an impulse received by the visual cortex, then the sum total of activities going on here might again be expressed by *V* plus *V* plus *V*, and so on. In like manner, *A* plus *A* plus *A* would express the activities in the auditory area. Those sensory elaborations developing in a separate, specific region of the endbrain would represent *monesthetic* or *single sense syntheses*. The combination of these several types of monesthetic syntheses with each other may be represented by the expression *T* (tactile) plus *V* (visual) plus *A* (auditory) plus *O* (olfactory) plus *G* (gustatory). In this manner opportunity is afforded for an enormous expansion of consciousness and experience. Sensory combinations thus created are *polyesthetic syntheses* for which the cerebral hemispheres make provision. The greater development of the human hemispheres as compared with the hemispheres of other animals underlies the correspondingly great expansion of individual behavior which distinguishes man among the vertebrates.

The endbrain also plays an important part in the regulation of generic behavior, inasmuch as certain ancient regions of the telencephalon participate in the control of inherent, habitual and ancestral reactions which are not acquired through individual experience, but represent a phyletic inheritance necessary to the maintenance and perpetuation of life. These ancient parts of the cerebral hemispheres thus intimately related to generic behavior, constitute the basal ganglia or corpora striata. Contrasted with the cerebral cortex the corpora striata are archeal, while the pallium of the hemispheres is of recent development. It is of interest to observe the manner in which these two essential portions of the endbrain have maintained their relations with each other during the process of evolution which eventually gave the

cerebral cortex dominance over all other parts of the brain. It is also important to note in what manner the relative development of the basal ganglia and cerebral pallium has affected behavioral reactions, and to what extent the more primitive generic behavior has been modified by or subjugated to the more highly organized individual behavior.

The Endbrain in the Several Classes of Vertebrates. A brief review of the endbrain in the different classes of vertebrates will elucidate the relation of this portion of the encephalon to the two major types of animal behavior.

In *cyclostomes* the endbrain is, perhaps, the simplest. It does not in the strict sense present any well defined cerebral pallium. The telencephalon consists of an olfactory bulb in connection with an olfactory lobe, separated from each other by a slight lateral constriction. It is difficult to recognize

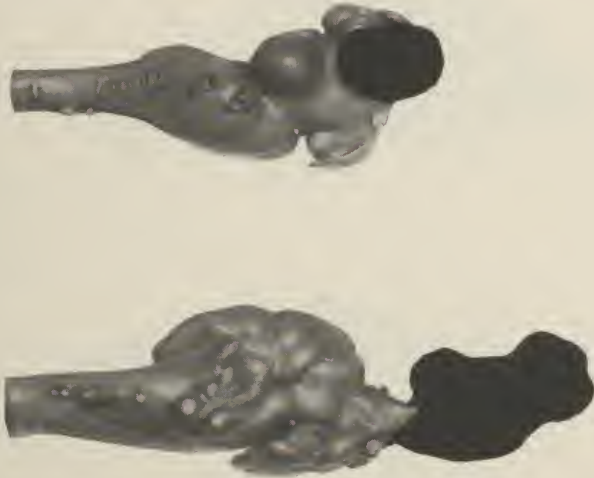


FIG. 439.—Diagrammatic representation of the telencephalon (endbrain) in the vertebrate series, lateral view. Darkened area.

Petromyzon (lamprey) above. Scyllium canicula (dog-fish) below.

a definite hemisphere, since the separation of the endbrain into two equal halves is merely indicated by the presence of a shallow midsagittal groove. In the caudal portion of the telencephalon close to its connection with the interbrain, there appears a specialized collection of cells, the *epistriatum*. This structure seems to serve as a primitive pallium. It receives fibers from the olfactory lobe which in turn is in communication with the olfactory bulb. The olfactory bulb and lobe together represent the primary and secondary centers for the sense of smell. For this reason the *epistriatum* may be regarded as the primitive olfactory cortex or *olfactory archipallium*. The floor of the caudal portion of the endbrain consists of the basal ganglion or corpus striatum which contains many large pyramidal cells of the motor type. By its connection it serves as the efferent part of the reflex arc which transmits the impulses necessary to the most complex movements of which

these animals are capable. Among the chief elements in the primitive vertebrate endbrain are the olfactory bulb and lobe. They receive and transmit those sensory impressions which are added to the animal's consciousness in the interest of detecting, approaching and selecting food. Provision for the necessary elaboration of these olfactory impressions is afforded by the epistriatum, while the basal ganglion acts as the motor division of the central mechanism through which these sensory impressions are transformed into somatic motor activities. The basal ganglion, however, is in communication not only with the epistriatum, but also with the thalamus, and thus becomes responsive to impulses other than those received from the olfactory parts of the brain. It is influenced by visual, gustatory and somesthetic impulses. The character of the behavioral reaction in cyclostomes is of the



FIG. 440.—Diagrammatic representation of the telencephalon (endbrain) in the vertebrate series, lateral view. Darkened area.

Salmo salar (salmon) above. *Rana esculenta* (frog) below.

generic type. Although it expresses in an effectual manner the efforts essential to maintain life and propagate the species, it represents nothing characteristic of individual behavior.

In *selachians*, the endbrain differs considerably in form from the cyclostomes. The olfactory bulbs have become much further separated from the olfactory lobe and are connected with the latter by means of a thin stem, the *olfactory stalk*, which is the beginning of the olfactory tract. This stalk contains a small tubular canal through which the ventricle of the olfactory lobe is in communication with the ventricle of the olfactory bulb. In other respects the endbrain shows but little advance. The hemispheres are foreshadowed in their ultimate form by the presence of a midsagittal groove; they are, however, only partially separated from each other. Extending from the cephalic extremity of the endbrain and along the dorsal surface of

the optic tract and optic bulb is a cranial nerve which, in some of the higher forms, has disappeared. This is the *nervus terminalis*. The endbrain in selachians consists of the olfactory bulb, the olfactory lobe, the epistriatum and the basal ganglion which maintain relatively the same primitive conditions as in the cyclostomes. The behavioral reactions of these animals are essentially of the generic type.

In *teleosts and ganoids*, the olfactory bulb and lobe hold a relation similar to that in selachians. The interhemispherical sulcus is somewhat more clearly marked. The telencephalon consists of the olfactory lobe, olfactory bulb, epistriatum and basal ganglion. The roof of the endbrain in the bony fish is a thin, membranous structure. As yet, however, no differentiation is evident in this telencephalic roof which even foreshadows the development

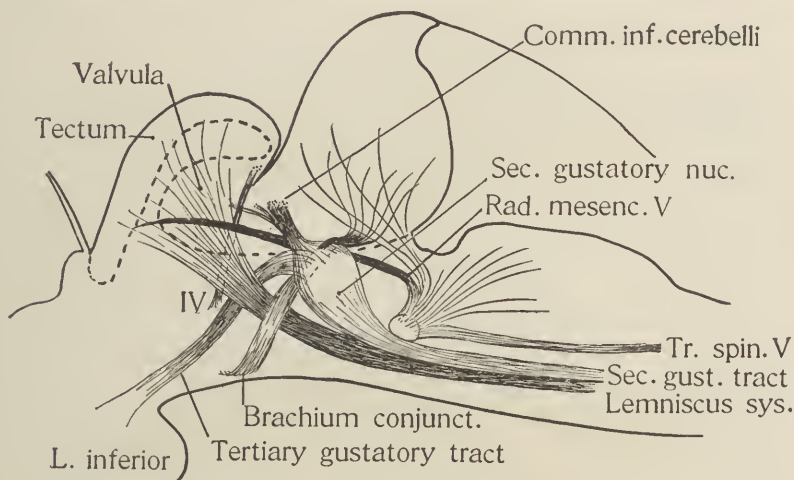


FIG. 441.—The relations of the cerebellum, brachium conjunctivum and gustatory tracts in a ganoid fish, the sturgeon. (Johnston.)

of a cerebral cortex. The nearest approach to a cerebral pallium in the fish is the epistriatum which serves in an olfactory capacity. Further than this, no signs of pallial development are found in any of the fish, and the type of their behavior is characteristically generic. Critical changes looking toward the establishment of a cerebral pallium make their appearance in the next higher order, the amphibia.

In *amphibians*, a change in the form of the endbrain is caused by the appearance of a deep longitudinal fissure in the midsagittal line which divides the more caudal portion of the telencephalon into the two distinct hemispheres. The olfactory lobes, however, do not participate in this division and are separated from each other merely by the longitudinal sulcus observed in the fish. The appearance of the longitudinal fissure is decisive in the differentiation of one hemisphere from the other. Each half of the endbrain now consists of a partially differentiated hemispherium, an olfactory bulb, an olfactory lobe, an epistriatum and a corpus striatum.

The epistriatum appears to be particularly active in the first step toward the formation of an actual pallium. Epistriatal cells have undergone a rapid migration into the partially infolded roof membrane which now constitutes the mesial and dorsal walls of either cerebral hemisphere. This region in the cerebral cortex of amphibia contains three distinct layers:

1. An innermost or epithelial layer consisting of large triangular or cuboidal cells which form the lining of the ventricle.
2. A layer of pyramidal cells which appear to be homologues of the pyramidal cells in mammals.
3. A plexiform layer made up of smaller, stellate or fusiform cells.

This stratified cortex which is in direct connection with the corpus striatum, constitutes the archipallium or primitive cerebral cortex and is

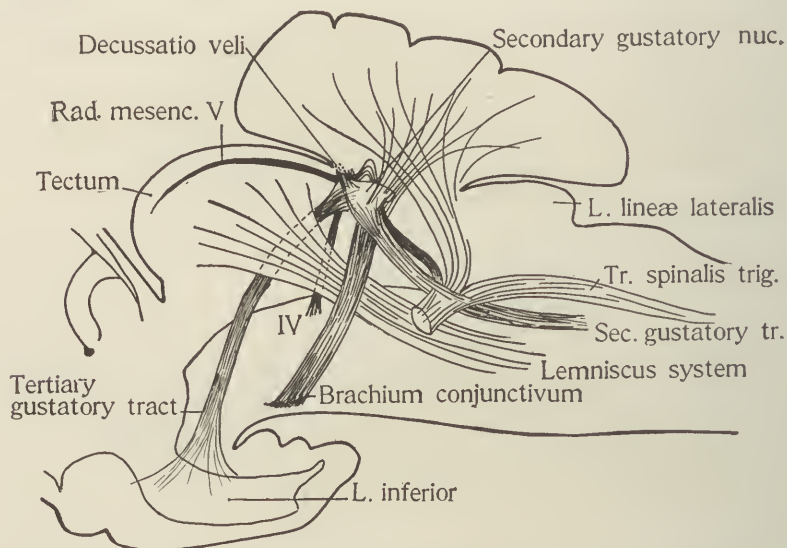


FIG. 442.—The relations of the cerebellum, brachium conjunctivum and gustatory tracts in a selachian, the dog-fish. (Johnston.)

considered by most authorities to be related to the olfactory sense. The amphibia in general show a wider range of behavioral adaptation, although their reactions are largely of the generic type.

In *reptiles*, the differentiation of the cortex is carried a step further by the formation of a definite *hippocampal* or *olfactory pallium* which is extensive enough to deserve the term *rhinencephalon* (olfactory brain). This cortex consists of five layers:

1. A superficial plexiform layer, made up for the most part of dendrites and axones.
2. A layer of pyramidal cells, the homologues of the pyramidal cells in mammals.
3. A deep plexiform layer.
4. A layer of white substance.
5. An ependymal layer.

The white substance of the cortex contains short and long ipsilateral association fibers as well as crossed association fibers connecting one hemisphere with the other. These crossing fibers have inaccurately been termed the corpus callosum, although no such structure actually exists in the endbrain of the lower vertebrates. The interhemispherical fibers belong exclusively to the commissural system of the olfactory cortex.

According to some authorities the white substance of the cortex contains projection tracts, that is, systems of fibers which connect the cerebral pallium with the segmented portions of the neuraxis. One fasciculus in particular has been regarded as representing such a projection system. This is the *sagittal fasciculus* or *septo-mesencephalic tract*. It seems likely, that this fasciculus represents, in part at least, the anterior pillars of the



FIG. 443.—Diagrammatic representation of the telencephalon (endbrain) in the vertebrate series, lateral view. Darkened area.

Alligator mississippiensis (alligator) above. Columba (pigeon) below.

fornix and constitutes the most primitive projection pathway from the cerebral cortex. This pathway establishes a connection between the primitive hippocampal formation (rhinencephalon), and the posterior lobe (corpus mammillare). By this means, efferent impulses find their way from the sensory portion of the rhinencephalon in order to effect motor responses. The hippocampal formation appears to be the first part of the cerebral cortex which is differentiated.

In amphibians and reptiles, therefore, the cerebral pallium has been added to the endbrain in the interest of expanding olfactory experience. It provides an olfactory mechanism adapted to new requirements in searching for and procuring food. These animals have partially or completely assumed the functions of air breathing, and their olfactory apparatus has

been modified by the change in the medium through which olfactory stimuli are transmitted. The olfactory sense in the land-living animal has in all probability extended the scope of its application. It is capable of detecting stimuli from many more sources than is true of aquatic life. Olfactory sensibility as a whole has multiplied its significance in the terrestrial vertebrates not only in connection with the quest for food, but also in protective reactions of offense and defense as well as in the sexual life. The behavioral reactions of the amphibia and reptiles have undoubtedly been amplified by this advance in the organization of olfactory sensibility. Their behavior, however, is essentially of the generic type and manifests but little individual modification.

In *birds*, the endbrain consists of two large cerebral hemispheres. The pallium is but little more differentiated than in reptiles and amphibians. It adheres closely to the lateral and dorsal aspects of the corpus striatum. Upon its mesial surface the striate body is separated from the pallium by the interposition of the cleft-like lateral ventricle. This is the only portion of the avian cortex which has thus far received extended study. It does not appear to belong to the hippocampal formation, nor does it seem in any way homologous with the more primitive olfactory portions of the brain. It may represent the addition of a new association area connected with vision. The arrangement of the cells in the mesial portion of the cortex and the relatively great development of the corpus striatum in birds, seem to indicate more extensive adaptations in generic behavior. The mesial cortex consists of five layers:

1. The plexiform layer, which contains dendrites and axones.
2. The layer of small stellate cells.
3. The layer of large stellate or pyramidal cells, homologues of the pyramidal cells in mammals.
4. A deep layer of stellate cells.
5. The ependymal layer.

The corpus striatum consists of several portions, one of which is situated above the main body of the ganglion, and is regarded as the epistriatum. The appearance of several prominent fasciculi in the corpus striatum subdivides this part of the brain into the *hypostriatum*, *mesostriatum* and *ectostriatum*. The epistriatum probably represents an olfactory portion of the telencephalon which is rudimentary in development. The visual and somesthetic types of sensibility play by far the most important part in the behavioral reactions of birds. The object of the avian hemispheres is apparently to provide for ample polyesthetic associations chiefly dependent upon body sense, hearing and sight. The great size of the corpus striatum is indicative of the many varieties of generic behavior manifested by birds. Among these may be mentioned the various behavioral reactions seen in mating, nesting, protection of the young and migration, as well as actions in quest of food, in defense and attack. Almost every species of bird has its series of motor activities which assist in identifying it, and which represent special modifications of generic behavior. On the other hand, individual differences between birds of the same species are slight.

The connections of the cerebral cortex in birds are not well understood, although the principal fasciculus of the endbrain, the *tractus septo-mesencephalicus*, seems to afford a direct connection between the optic lobe of the midbrain and the telencephalic pallium. Connection between the corpus striatum and cerebral pallium is established by a well defined radiation. This radiation also connects the corpus striatum with the optic thalamus. The chief efferent connection of the corpus striatum with the central axis is provided by the basal bundle which contains descending fibers from the large cells of the striate body. This bundle, the *fasciculus basalis*, appears in reptiles, amphibians and fish, and serves them all in a similar capacity. It is part of one of the most ancient motor pathways in vertebrates.

In *mammals*, the cortex attains its highest development. In the simpler forms, the monotremes and marsupials, it presents some features in which it resembles the cortex of reptiles; such for example, as the reappearance of the hippocampal formation, which seems to have been in part suppressed in birds. In monotremes and marsupials, the corpus callosum is absent. The interhemispherical connection is accomplished by the hippocampal and anterior commissures. The hippocampal formation constitutes the rhinencephalon, which is separated from the rest of the cortex, by the *external rhinic fissure*. In mammals there is a pronounced expansion of the cortical surface upon the mesial, lateral and basal aspects of each hemisphere. The principal development appears in the addition of the *neopallium*, which represents all of the more recently acquired cortical areas in contradistinction to the more primitive olfactory brain, the *archipallium*. The acquisition of the neopallium has followed the law of telencephalization, which permitted the addition of new cortical areas in direct response to functional demands. When the requirements of vision, hearing and body sensibility could no longer be satisfied by the primitive mechanism provided for them, their entire sphere of influence was moved forward into newer parts of the brain capable of a greater degree of expansion. It is for this reason that the neopallium does not consist of indiscriminately scattered areas, but comprises a number of discrete functional regions. Among the rodents, four areas of the cerebral cortex have been differentiated: (1)



FIG. 444.—Diagrammatic representation of the telencephalon (endbrain) in the vertebrate series, lateral view. Darkened area.

Lepus cuniculus (rabbit) above. *Canis familiaris* (dog) below.

The motor area; (2) the visual area; (3) the sensory area; and (4) the olfactory area. In carnivores the types of cortex which have been identified comprise a motor, a visual, an olfactory, an auditory and a somesthetic area.

The pallium of the endbrain in mammals, like the cortex of other supra-segmental organs, is a stratified structure. In general it consists of six layers:

1. The outermost or plexiform layer.
2. The layer of small pyramidal cells.
3. The layer of medium-sized pyramidal cells.
4. The layer of large pyramidal cells.
5. The layer of ovoid or polymorphous cells.
6. The layer of white matter.

The white matter in the endbrain of mammals shows a correspondingly great increase in size in direct relation to the increase in the neopallium. The medullary increase makes provision for many types of association taking place between the various forms of sensibility. A large portion of this white matter consists of association fibers whose axones are short and serve to



FIG. 445.—Brain of rabbit (*Lepus cuniculus*).

Type of lissencephalic cortex.

connect adjacent areas of the same hemisphere. Other association axones are much longer and associate parts of the brain separated by considerable distances. These are the long association fibers. Collectively, the long and short association fibers constitute the intrahemispherical association tracts. In all of

the mammals higher than the marsupials an increasing number of fibers enter the white matter in order to establish a communication between the two hemispheres. These axones constitute the interhemispherical association system composing the corpus callosum. A third system of axones enters the white matter, the *projection fibers*. They connect the cerebral cortex with the segmented portions of the central axis by ascending and descending fibers. The ascending fibers are afferent and convey impulses to the cerebral cortex from the several receptors of the body. The descending fibers are efferent and bear impulses closely associated in the motor activities of the nervous system either to the brain-stem and spinal cord or to the cerebellum. These projection fibers are assembled from several different areas in the neopallium to form a dense bundle near the base of the brain. This bundle constitutes the *internal capsule*.

The primitive efferent pathway from the rhinencephalon or olfactory brain is still present in mammals as the *fornix* which connects the hippocampal formation with the mammillary body. It provides an efferent pathway to the midbrain and thus to the lower portions of the central axis.

The corpus striatum which in the birds had become differentiated to form a mesostriatum, a hypostriatum and an ectostriatum, now presents still more definite subdivision; *i.e.*, the *lenticular* and *caudate nuclei*. The lenticular nucleus consists of two portions, the *globus pallidus* or *paleostriatum*, and the *putamen* or *neostriatum*. The neostriatum in all probability corresponds to the ectostriatum of reptiles and represents a relatively late addition to the basal ganglion. The caudate nucleus appears only in those forms which have a well marked internal capsule. It is a recently acquired portion of the corpus striatum.

Certain surface modifications serve to increase the cell-containing area of the hemispheres and give it maximum possibilities of expansion. These changes comprise the formation of convolutions with intervening fissures or sulci. The importance of these convolutions in increasing the cell-containing substance of the cerebral pallium is seen in comparing a series of mammalian brains. In many mammals the surfaces of the hemispheres are smooth and the brain in consequence is called *lissencephalic*. The brains of the monotremes, many of the marsupials and rodents, the insectivores and bats

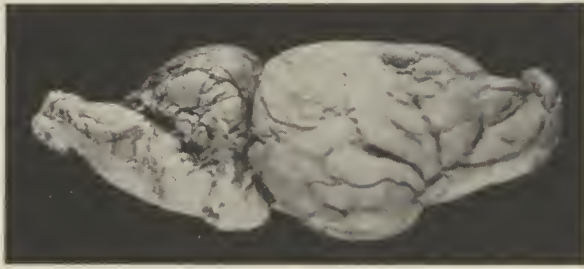


FIG. 446.—Brain of kangaroo (*Macropus Grayi*).
Type of gyrencephalic cortex.

are lissencephalic. All other mammals, including some marsupials and rodents, all of the cetacea, sirenia, ungulates, carnivores both fissiped and pinniped, as well as the primates, have a cerebral cortex which presents more or less irregular convolutions. Such brains are known as *gyrencephalic*. A comparison of the lissencephalic with the gyrencephalic animals shows at a glance the significance of cerebral convolution in relation to the complexity of behavioral reactions.

The lissencephalic endbrain of a rabbit is pyriform in shape, tapering toward the cephalic extremity where it overlies the olfactory bulbs. The greatest expansion is in the dorso-caudal portion where the hemispheres come into relation with the cerebellum. The entire surface is smooth. The superior longitudinal fissure divides the brain into two equal halves which are in apposition, so that each hemisphere has a lateral, a mesial and a basal surface. The brain of a dog, which is gyrencephalic, when compared with that of the rabbit presents a marked contrast. The two hemispheres of the dog are well defined, and the surface is much more complex, due to the appearance of a number of convolutions and fissures. There is a considerable expansion of the frontal pole as well as of the occipital pole in the canine

brain. The mesial surface shows a similar tendency toward the formation of gyri whose apparent office is to increase the cell-containing area. A comparison of the behavior of the rabbit and the dog shows at once that while the rabbit's reactions are largely those of generic behavior more or less modified by a few individual adaptations, the reactions of the dog, although presenting the fundamental generic characters, are greatly modified by behavior which is individualistic and has resulted from the complex associations imposed by domestication. Of these two types of animals there can be scarcely a doubt that the amount of individualization is greater among dogs than among rabbits.

Almost as striking a difference is seen in the comparison of the canine brain with that of the higher anthropoids. The distinctly advanced development seen in the frontal and occipital poles and also in the temporal regions of the chimpanzee is pronounced. The dimensions of the brain are relatively

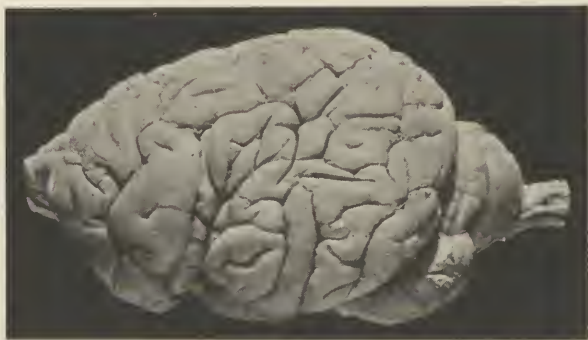


FIG. 447.—Brain of Sea-lion (*Zalophus californianus*).
Type of gyrencephalic cortex.

greater. The fissures and convolutions are more complex, numerous and prominent. This applies equally to the mesial and lateral aspects of the brain. A good idea of the increase in the complexity of the neopallium is seen in the accompanying illustrations showing the lateral surface of the cerebral hemisphere.

The extent to which the chimpanzee may be trained for purposes of exhibition is well known. Its actions in many respects are almost human. The chimpanzee may be taught to perform acrobatic feats which are perhaps impossible for the most skilled human athletes. It may also be instructed in the performance of numerous skilled acts involving the employment of the upper and lower extremities and of the whole body. In fact, the degree to which this animal may be trained far exceeds that of any other vertebrate. Many of the mammals, including the marsupials, ungulates, rodents, carnivores, both fissiped and pinniped, may be taught to perform complex and highly skilled acts. All of these performances are indicative of a capacity for the individual to acquire distinctive characteristics which are to be classified in the individualistic group of behavioral reactions.

That the greatest number of individualistic reactions is attained by the animals possessing the most complex neopallium, becomes almost self-evident. Its final proof is given by the cerebral hemispheres of man. The human hemisphere shows a marked increase in relative volume, in complexity and in the richness of its fissures and convolutions when compared with that of the highest apes. An especial advance has been made in the

frontal region which is regarded as the seat of the highest mental faculties. This region is not only larger than in the anthropoid brain, but also shows a greater number of convolutions and fissures. The occipital pole has also increased in the size and complexity of its convolutions. The intermediate zone between the two poles is broader and richer in fissures and gyri. The temporal pole of the brain has increased greatly in size and complexity.

All of these features in the endbrain of man indicate the consummation of the process which has led to the extreme differentiation of individualistic behavior.

In man the corpus striatum still is a prominent part of the hemisphere and plays an important rôle in the activities of the individual; but in all probability it has delegated some of its functions to the cerebral cortex, or in any event has become subordinated in action to the dominant neopallium. In the human cerebral cortex seven layers of cells are recognized, as follows:

1. A plexiform layer.
2. A layer of small pyramidal cells.
3. A layer of medium sized pyramidal cells.
4. An external layer of large pyramidal cells.
5. A layer of stellate cells.
6. An internal layer of large pyramidal or giant cells.
7. A layer of spindle-shaped cells.

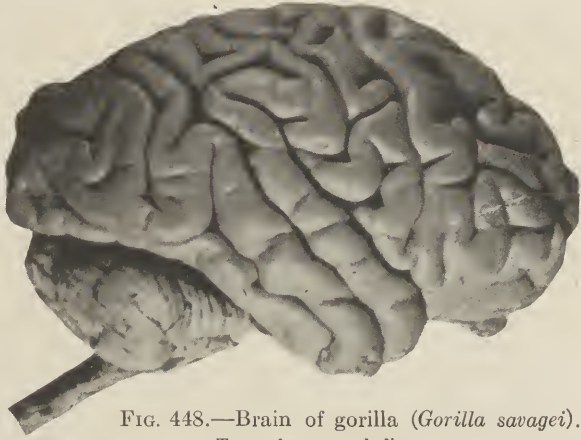


FIG. 448.—Brain of gorilla (*Gorilla savagei*).
Type of gyrencephalic cortex.

The cerebral cortex, which in its inception was entirely devoted to the correlation of olfactory and perhaps gustatory impulses, as seen in the amphibia and reptiles, subsequently came to serve the purposes of all types of sensibility. Ultimately it afforded an area wherein the most complex correlations and associations of the various types of sensory perception occurred, thereby constructing the foundations for the higher psychic faculties which express themselves in the most highly differentiated of individualistic behavior—that seen in man. The endbrain, on the other hand, through the corpus striatum still exercises a control over the reactions of generic behavior. The parts of the telencephalon which require special study are the basal ganglia, the cerebral cortex, the medullary substance and the ventricles.

CHAPTER XXXVI

THE ENDBRAIN

SURFACE ANATOMY OF THE CEREBRAL HEMISPHERES

Surface Appearance of the Hemispheres. Each hemisphere presents a frontal, an occipital and a temporal pole. The *frontal pole* is at the extreme cephalic end of the hemisphere, while the most projecting portion of the caudal extremity is the occipital pole. The tip of the hemisphere which occupies the temporal fossa of the skull is the *temporal pole*. The ventral surface of this portion of the brain presents an indenture, the petrosal depression. This is produced by the elevation of the petrous portion of the temporal bone, which corresponds to the position of the superior semicircular canal.

In certain well hardened specimens there is, near the occipital pole, a broad and shallow groove marking the commencement of the lateral sinus. This is generally more pronounced upon the right side than the left, inasmuch as the right sinus is usually of greater size. Brains hardened in situ present on the ventral surface about one-third of the distance from the occipital to the temporal pole a slight indentation. This is the *pre-occipital notch* (*incisura preoccipitalis*). Its distance from the occipital pole is about 3.75 cm. ($1\frac{1}{2}$ inches). The notch is more prominent in the child than in the adult; it is produced by the fold of the dura over the parieto-mastoid suture.

The surface of the brain on its mesial, ventral and lateral aspects is complexly modelled, owing to the appearance of irregular, tortuous elevations whose relief is increased by the presence of deep clefts or grooves which intervene between them. The irregular elevations are the *convolutions* or *gyri*, while the intervening furrows are the *fissures* or *sulci*. These convolutions and fissures present much variation in the detail of their arrangement, not only in different individuals, but also in the hemispheres of the same brain. In general, however, the fissures and convolutions of a normal human brain have an arrangement which follows a definite plan. It is possible in consequence of this arrangement to identify corresponding convolutions and fissures in all human brains.

THE FISSURES OF THE CEREBRAL HEMISPHERES

Cerebral Fissures. The fissures differ not only in their depth, but also in their relations. Some of these fissures are complete, due to the fact that they involve the entire thickness of the cerebral vesicle and in consequence produce elevations on the wall of the ventricular cavities. These complete or total fissures are five in number:

1. The *hippocampal fissure*, which causes a projection in the temporal horn of the lateral ventricle, known as the *hippocampus major*.

2. The *calcarine fissure*, which in its anterior portion causes the appearance of the calcar avis at the junction of the occipital and temporal horns of the lateral ventricle.

3. The *collateral fissure*, which in its cephalic portion produces a protrusion of variable size in the lateral ventricle, called the *collateral eminence*.

4. The *chorioidal fissure*, which during fetal life causes an eminence to appear in the body of the lateral ventricle.

5. The *parieto-occipital fissure*, which likewise in fetal life gives rise to an invagination causing a prominence to appear in the occipital horn of the ventricle.

These fissures appear in the early development of the hemispheres. Other fissures, less deep than the complete or total fissures, make a later appearance and are known as *incomplete fissures*. They do not produce impressions upon the wall of the ventricle. In depth they vary from 1 mm. to 2.5 cm. with an average of 1.5 cm.

The height of the convolutions usually exceeds the width. The larger and longer gyri are in many instances connected by short bridges, the *annectant gyri*. These annectants may cross at the bottom of the intervening fissure and be entirely hidden from view. When such is the case they are called *gyri profundi*. They may, however, be superficially placed and participate in the complexity of the surface appearance of the brain. These are the *gyri transversi*.

Interlobar Fissures. For purposes of description the surfaces of the cerebral hemispheres are divided into certain topographical areas which are called lobes. The lines of division between these lobes are determined by the fissures or sulci.

The lobes of each hemisphere determined by these boundary lines are: (1) The frontal lobe; (2) the parietal lobe; (3) the temporal lobe; (4) the occipital lobe; (5) the limbic lobe; (6) the insula; (7) the olfactory lobe. The fissures which serve to demarcate these lobes are: (1) The fissure of Sylvius; (2) the central fissure; (3) the parieto-occipital fissure; (4) the collateral fissure; (5) the calloso-marginal fissure; (6) the circular sulcus of the insula; (7) the calcarine fissure.

THE FISSURE OF SYLVIVS (*fissura cerebri lateralis*). The fissure of Sylvius is the most conspicuous sulcus in the human brain. It appears on the *norma lateralis* between the frontal and parietal lobes above and the temporal lobe below. It is the first of all the fissures to make its appearance in the development of the brain. Its most mesial portion is marked by a depression, the *vallecula Sylvii*, which opens upon the anterior perforated space. The fissure presents a stem which passes horizontally out from the base of the brain toward the lateral surface of the hemisphere, forming a deep cleft which separates the orbital area from the temporal pole. Upon reaching the lateral surface, the Sylvian fissure divides into a short anterior horizontal branch, a longer anterior ascending branch and a long posterior

branch. The anterior horizontal branch (*ramus anterior horizontalis*) is about 2 cm. in length. It passes upward and slightly forward into the caudal portion of the inferior frontal convolution. The posterior branch (*ramus posterior*) is the main lateral continuation of the fissure. It extends backward and slightly upward for a distance of 8 cm. This part of the fissure forms the boundary between the frontal and parietal lobes above, and the temporal lobe below. It usually ends by dividing into two short arms, one of which enters the parietal lobe, while the other extends downward into the temporal lobe. These three divisions of the Sylvian fissure upon the lateral surface demarcate certain portions of the inferior frontal, parietal, and superior temporal convolutions. A portion of the inferior frontal convolution cephalad of the horizontal branch of the fissure constitutes the *pars orbitalis* or the *orbital operculum*. The portion of the convolution between the horizontal and ascending branches constitutes the *pars triangularis* or *intermediate frontal operculum*. Caudal to the ascending branch of the Sylvian fissure is located the *pars basalis*.

These two branches of the Sylvian fissure may arise independently from the main fissure, or by a common stem. In some instances the ascending branch is absent, in which case the intermediate frontal operculum is wanting.

The other convolutions adjacent to the Sylvian fissure are known respectively as the *superior frontal operculum*, *parietal operculum* and the *temporal operculum*, each of which constitutes a portion of the overhanging surface of the cerebral cortex concealing from view the sunken portion of the cerebral cortex constituting the island of Reil. These relations of the Sylvian fissure are dependent upon the development of the parts which surround it during the embryonic and fetal periods. After the third fetal month the lateral surface of each hemisphere presents an area which is considerably depressed. This is the *Sylvian fossa*. The floor of this fossa corresponds to the insula or island of Reil in the adult brain. The fossa is surrounded by a cephalic, a dorsal and a ventral portion of the cerebral surface which gradually become elevated and begin to approach each other. By the fifth month the shallow fossa of Sylvius is replaced by a triangular depression which is overhung by the formation of certain opercula or lids. These opercula at first are three in number, namely, the *frontal operculum*, the *parietal operculum* and the *temporal operculum*. As they grow closer together the insula becomes concealed in much the same manner that an eye is concealed by the closure of the eyelid. In this way the Sylvian fossa, which at first appears as a small depression on the lateral aspect of the hemisphere, becomes a sunken part of the cortex concealed by the overhanging opercula formed in the frontal, parietal and temporal regions. The frontal operculum subsequently becomes subdivided by the horizontal and ascending arms of the Sylvian fissure into the *pars orbitalis*, the *pars triangularis* and the *pars basalis*.

THE CENTRAL FISSURE (*sulcus centralis* or *fissure of Rolando*). This fissure extends across the lateral convex surface of the hemisphere in such a way as to interrupt the general longitudinal course of the gyri and sulci

of this region. It is bounded by two oblique convolutions known as the precentral and postcentral gyri. The fissure begins near the vertex, usually in the highest part of the hemisphere slightly behind the midpoint of the superior longitudinal fissure. It then passes downward, outward and forward to end near the middle of the fissure of Sylvius whose posterior limb it sometimes, though rarely, joins. This junction when established is effected through a small sulcus called the *anterior subcentral sulcus*, which, however, in the majority of cases, is separated from the lower end of the central fissure by an annectant gyrus connecting the two central convolutions at their base. The fissure of Rolando as a rule extends to the mesial border of the hemisphere, sometimes stopping short of this line. In most cases it presents a hook-like continuation caudad. The fissure presents at the junction of its upper and middle thirds a distinct curve with its concavity directed forward. The upper and lower limits of this bend in the fissure constitute the superior and inferior genu respectively. The cortex occupying this recess is important from the fact that it represents the part of the precentral gyrus which forms the motor center of the arm. The lower extremity, or the inferior genu of the fissure, descends almost vertically to terminate in close relation to the fissure of Sylvius. The angle of the inclination of the central fissure with the mesial plane of the adult brain averages 71.7 degrees.

The fissure of Rolando has been found interrupted near its middle in the brains of several distinguished men. This anomaly, however, is rare and when present usually affects but one hemisphere. Its frequency is about 1 per cent of all cases examined. The entire length of the Rolandic fissure is 8 cm., when the measurement is made along a straight line on the surface of the brain between its two extremities. It is relatively longer and more curved in the anthropoid apes than in man. In one instance this fissure was double, the two central fissures being separated by a convolution called the *gyrus Rolandicus*. This convolution extended the entire length of the two Rolandic fissures. The condition reported was present in both hemispheres of the same brain.

THE PARIETO-OCCIPITAL FISSURE. This fissure is best seen on the mesial surface of the hemisphere, where is formed a deep cleft constituting the internal portion of the parieto-occipital fissure. It extends downward and a little forward of the superior margin of this surface near the posterior extremity of the corpus callosum, at which point it usually joins the calcarine fissure, thus forming a Y-shaped fissure. Enclosed between the calcarine and the parieto-occipital fissures is the wedge-shaped portion of the occipital lobe, the *cuneus*. On the lateral surface the parieto-occipital fissure is continued transversely for a short distance, usually about 12 mm. This constitutes the external portion of the parieto-occipital fissure. A line connecting this portion of the fissure with the preoccipital notch establishes an arbitrary boundary between the occipital lobe behind and the temporal and parietal lobes in front. Upon separating the convolutions bounding the parieto-occipital fissure, it will be seen that it does not actually join

the calcarine fissure, but is separated from the latter by the cuneo-limbic annectant gyrus. Several other annectant gyri cross the parieto-occipital fissure in several portions of its course, usually at the junction of its upper and middle thirds. In anthropoids the external part of the parieto-occipital fissure is concealed within a deep transverse cleft known as the *fissura simiarum*, which intervenes between the parietal and occipital lobes. It is doubtful whether any fissure in the human brain corresponds to this simian fissure. Elliot Smith maintains that it is present in a great majority of human brains as a curved sulcus which he calls the *sulcus occipitalis lunatis*, situated on the lateral aspect of the occipital lobe.

THE COLLATERAL FISSURE. This is a sulcus on the mesio-ventral surface of the brain that lies beneath and parallel to the anterior division of the calcarine fissure. It extends forward to the tip of the temporal lobe. The middle portion of the fissure produces a projection in the temporal horn of the lateral ventricle called the *collateral eminence*. The anterior portion of the fissure is often indistinct or is separated from the middle part. In conjunction with the *incisura temporalis*, in some cases it partially separates the enlarged cephalic extremity of the hippocampal gyrus (pyriform lobe) from the temporal lobe. In certain instances these two fissures are continuous, forming, as in the simian brain, a distinct *rhinal fissure*.

THE CALLOSO-MARGINAL FISSURE (*the sulcus cinguli*). This is a deep fissure on the mesial surface of the hemisphere, beginning below the rostrum of the corpus callosum close to the anterior perforated space, and proceeding around the genu of the callosum in a course parallel to its body but separated from it by the gyrus cinguli. It is separated from the upper margin of the hemisphere by the large marginal gyrus as far back as a point somewhat behind the middle of the hemisphere. In this region it turns obliquely upward to terminate a short distance behind the commencement of the central or Rolandic fissure. It presents two portions, an anterior and a posterior division, which develop independently and are often distinct from each other at about the middle of the fissure. The anterior division is the *prelimbic fissure*, which sweeps about the genu of the corpus callosum. The posterior division of the fissure extends around the dorsal extremity of the central fissure and forms one of the boundaries of the paracentral lobule. This is called the *ramus marginalis*. The calloso-marginal sulcus marks off an area on the mesial surface of the anterior two-thirds of the hemisphere which is the *marginal convolution* of the frontal lobe. It separates this gyrus from the *callosal gyrus* of the limbic lobe whose posterior boundary is the somewhat variable sulcus known as the *postlimbic fissure*. This sulcus arches downward, following the general curve of the splenium of the corpus callosum. This fissure is also known as the *marginal fissure*.

SULCUS CIRCULARIS INSULÆ (*the limiting sulcus of Reil*). This is a shallow groove that surrounds the island of Reil and partially separates the sunken portion of the cerebral cortex from the deeper parts of the enclosing opercula.

THE CALCARINE FISSURE. This fissure is seen on the mesial surface of the hemisphere. It is a deep sulcus extending cephalad from the occipital pole



Fig. 449.—Norma medialis of the brain.

where it begins on the lateral surface as a T-shaped fork. It then proceeds forward and downward, ending below the splenium of the corpus callosum. As already described, it is confluent with the parieto-occipital fissure. A portion of the fissure caudal to this junction forms the posterior division of the calcarine fissure, while its cephalic portion forms the anterior division.

THE LOBES OF THE CEREBRAL HEMISPHERES

The Frontal Lobe (*lobus frontalis*). The frontal lobe (*lobus frontalis*) is the largest division of the hemisphere, including approximately one-third of its entire surface. Convolution appears on its lateral, ventral and mesial aspects. On the lateral surface it is bounded behind by the *central fissure of*

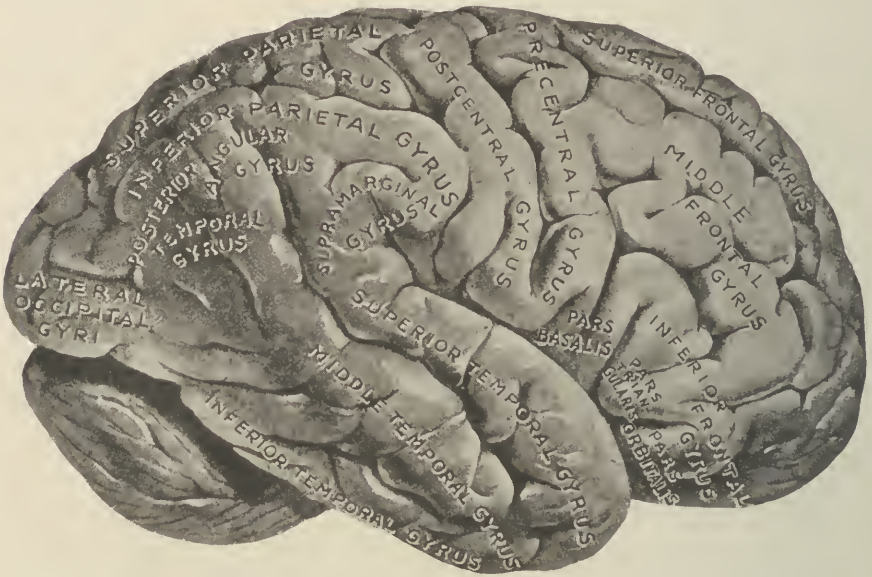


FIG. 450.—Brain viewed from the right.

Rolando which separates it from the parietal lobe. Ventrally the cephalic extremity of the *Sylvian fissure* separates it from the temporal lobe. The mesial representative of the frontal lobe is a hook-shaped convolution bounded by the calloso-marginal fissure, the *marginal convolution*. The frontal lobe on its basal surface includes the orbital area bounded behind by the transverse limb of the Sylvian fissure.

Upon the lateral surfaces three more or less constant fissures subdivide the frontal lobe. These are the precentral sulcus, the superior frontal and the inferior frontal fissures. The *precentral sulcus* occasionally appears as a continuous fissure parallel to the course of the Rolandic fissure with which it is coextensive. Its more usual appearance is in the form of two separate sulci, the superior and inferior precentral fissures. The *inferior precentral fissure* has a long vertical and a short transverse limb arranged either in the form of an L or a T. The vertical limb begins above the fissure of Sylvius in front of the Rolandic fissure. It extends upward and parallel with the fissure of

Rolando and is separated from it by the lower portion of the precentral convolution. The horizontal limb passes forward and slightly upward for a variable distance between the middle and inferior frontal convolutions.

The *superior precentral sulcus* continues upward to the cephalic boundary of the precentral convolution. It is parallel with the upper half of the Rolandic fissure but usually does not reach the mesial margin of the hemisphere. Frequently it receives the caudal extremity of the superior frontal sulcus, with which it then forms a T-shaped fissure.

The *superior frontal sulcus* extends forward from the superior precentral, having a course which is in general parallel to the dorsal border of the hemi-



FIG. 451.—Right cerebral hemisphere viewed from the left.

phere. It marks off the longitudinal marginal tract of the *superior frontal convolution*. The course of this fissure is often interrupted by annectant gyri which connect the adjacent borders of the superior and middle frontal convolutions.

The *inferior frontal sulcus* extends forward beginning at the interval between the horizontal and vertical limbs of the inferior precentral sulcus. It passes forward and downward toward the margin of the hemisphere. Its caudal extremity is often continuous with the inferior precentral sulcus.

CONVOLUTIONS ON THE LATERAL SURFACE OF THE FRONTAL LOBE. The convolutions upon the lateral surface of the frontal lobe determined by these fissures are the *precentral*, the *superior frontal*, the *middle frontal* and the *inferior frontal gyri*.

The *precentral gyrus* (*gyrus centralis anterior*) is also known as the ascending frontal convolution. It is bounded behind by the central fissure of Rolando, in front by the superior and inferior precentral fissures. Below, it is limited by the Sylvian fissure. Its upper extremity is continuous with the *paracentral lobule* on the mesial surface of the hemisphere, and anteriorly it is connected with all three frontal convolutions. It is predominantly associ-

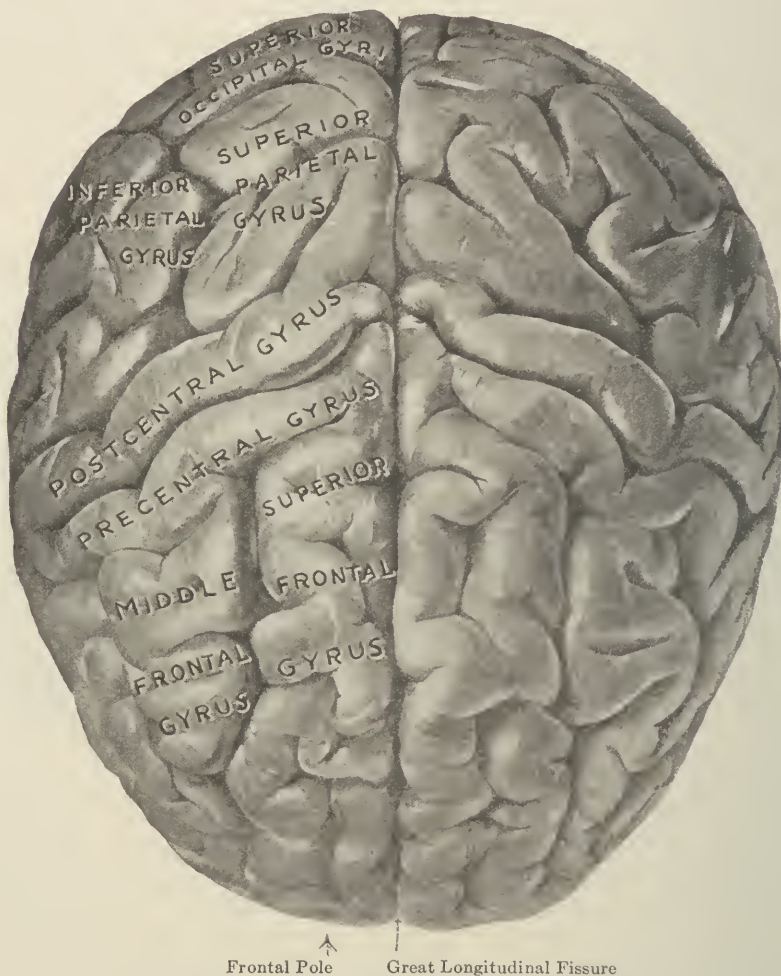


FIG. 452.—Cerebral hemispheres, viewed from above.

ated with motor functions representing the important cortical motor areas controlling the somatic musculature of the body.

The *superior frontal gyrus* is situated between the dorsal margin of the hemisphere and the superior frontal sulcus. Its course corresponds to the upper part of the hemisphere and is therefore much longer than the other frontal convolutions of the lateral surface. It is continuous on the mesial

surface with the marginal gyrus and joins the central convolution by means of a lateral bridge at the upper end of the precentral fissure.

The *middle frontal gyrus* is parallel to the superior frontal convolution from which it is separated by the superior frontal sulcus. The superior and inferior precentral sulci separate this gyrus from the central convolution, although a well marked deep annectant gyrus usually connects them.

The *inferior frontal gyrus* is the smallest of the three frontal convolutions and is situated in relation with the horizontal and ascending branches of the Sylvian fissure. These branches divide the inferior frontal gyrus into three parts; i.e., the *anterior frontal operculum* (pars orbitalis), the *intermediate frontal operculum* (pars triangularis), and the *posterior frontal operculum* (pars basilaris). The left inferior frontal gyrus is often called *Broca's convolution*, and is regarded as the motor speech center. It is more developed upon the left side in right-handed individuals. This greater development particularly affects the triangular part of the convolution which, when well developed, may entirely separate the horizontal and ascending branches of the Sylvian fissure. The inferior frontal gyrus is connected at its lower extremity with the lower end of the central convolution by an annectant gyrus. Its cephalic extremity passes around to the orbital surface of the frontal lobe.

CONVOLUTIONS ON THE MESIAL AND ORBITAL SURFACES OF THE FRONTAL LOBE. The *mesial surface* of the frontal lobe consists of a single convolution, the *marginal gyrus*, which is situated between the dorsal margin of the hemisphere and the calloso-marginal sulcus. It is a hook-shaped convolution continuous with the superior frontal gyrus above and the gyrus rectus of the inferior orbital surface below. Its caudal extremity is almost completely cut off from the rest of the gyrus by the ascending limb of the calloso-marginal fissure, the *ramus marginalis*. The portion of the convolution bounded in this way forms the *paracentral lobule*. This lobule is bounded behind by the upturned end of the calloso-marginal sulcus (ramus marginalis). In about 60 per cent of cases the paracentral lobule is incised by a mesial extension of the central fissure of Rolando. The marginal gyrus is often divided by an intermediate longitudinal fissure, the *medio-frontal sulcus*, which separates an upper and lower portion of the convolution. The cephalic extremity at its lower end is often incised by two or three short furrows, the *sulci rostrales*.

The *orbital surface* of the frontal lobe presents two fissures, the *olfactory* and the *orbital sulci*, which differentiate three chief convolutions; namely, the *inner*, *middle* and *outer orbital convolutions*. These subdivisions, however, are not separate convolutions, but rather portions of the superior and inferior frontal convolutions of the lateral surface of the brain.

The *olfactory sulcus* lodges the olfactory bulb and tract. Its course is parallel with the great longitudinal fissure. It marks off a narrow strip of cortex mesial to it and about 1 cm. in width. This is the *gyrus rectus* which is a part of the broad longitudinal region corresponding to the orbital surface of the superior frontal convolution.

The *orbital sulcus* includes a number of folds arranged in a variable manner, which differ not only in different brains but also upon the two sides of the same brain. Usually, however, the sulcus consists of two longitudinal limbs connected by a transverse furrow forming a common fissure in the shape of the letter H, K or X. The typical orbital sulcus divides this surface into an inner, outer and middle convolution by its longitudinal limbs. The middle gyrus is again subdivided into an anterior and posterior orbital gyrus.

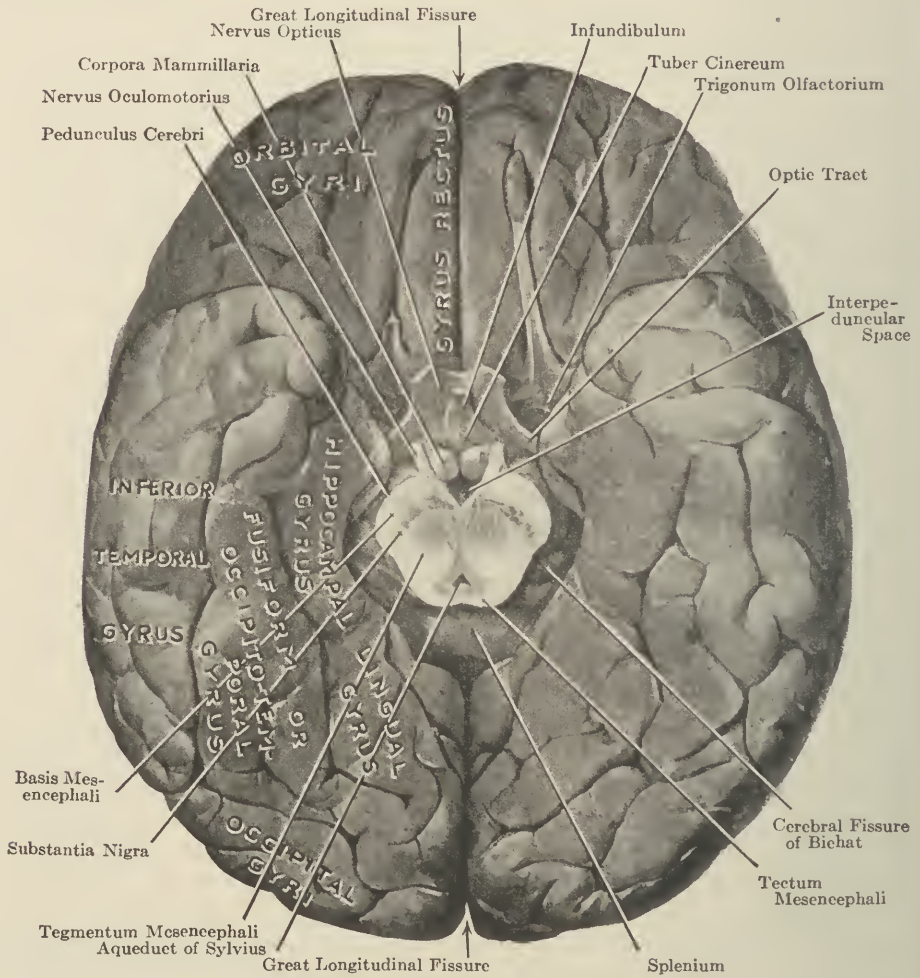


FIG. 453.—Basilar aspect of the brain.

The Parietal Lobe (*lobus parietalis*). This region of the brain comprises a large part of the hemisphere. It presents a lateral and a mesial surface. The lateral surface is the more extensive and has an irregular quadrilateral outline. It is bounded in front by the Rolandic fissure, below by the fissure of Sylvius, and behind by the imaginary line connecting the preoccipital notch with the external portion of the parieto-occipital fissure. Upon its lateral

surface the parietal lobe is divided by an interrupted fissure, the *intraparietal sulcus*, into three convolutions, the *postcentral*, *superior parietal* and the *inferior parietal gyrus*.

The *intraparietal sulcus* commences at the ventro-cephalic angle of the lobe a short distance above the Sylvian fissure with which it sometimes communicates. It extends for about an inch parallel with the fissure of Rolando and then curves backwards and slightly upwards across the parietal surface into the occipital lobe. The intraparietal sulcus usually appears as three distinct parts which in the usual case form the *inferior* and the *superior postcentral sulci* and the *horizontal intraparietal fissure*.

The *inferior postcentral sulcus* is situated behind and parallel to the lower part of the fissure of Rolando. It is separated in about 72 per cent of the cases from the superior postcentral sulcus.

The *superior postcentral sulcus* is situated behind and parallel with the Rolandic sulcus and dorsal to the horizontal limb of the intraparietal sulcus. It is limited behind by the lateral portion of the parieto-occipital fissure, beyond which, however, it continues into the occipital lobe forming a curved convolution, the *arcus parieto-occipitalis*.

The *horizontal intraparietal sulcus* passes backward and slightly upward. It separates the superior and inferior parietal convolutions. It is generally continuous at its cephalic extremity with the two postcentral sulci. In this form it presents a T-shaped fissure which subdivides the parietal lobe into three main convolutions. There is an occipital limb of the intraparietal fissure, which is usually a continuation of the horizontal limb and prolongs the intraparietal sulcus into the occipital lobe. In certain cases, however, it retains its independence from the ramus horizontalis intraparietalis being interrupted by a deep annectant gyrus.

CONVOLUTIONS ON THE LATERAL SURFACE OF THE PARIETAL LOBE. The convolutions of this portion of the brain are three in number: the postcentral, the superior parietal and the inferior parietal, the last being subdivided into certain accessory gyri.

The *postcentral gyrus*, or ascending parietal convolution, constitutes the caudal wall of the Rolandic fissure. It is bounded caudally by the postcentral sulcus in its two divisions. The lower extremity of this gyrus is connected with the precentral convolution in front and the inferior parietal gyrus behind by means of annectant gyri. The convolution is continuous dorsally with the paracentral lobule of the mesial surface between the termination of the calloso-marginal and Rolandic fissures.

The *superior parietal gyrus* is situated caudal to the superior postcentral sulcus and dorsal to the horizontal limb of the intraparietal sulcus. It is limited behind by the lateral portion of the parieto-occipital fissure, beyond which, however, it continues into the occipital lobe forming a curved convolution, the *arcus parieto-occipitalis*.

The *inferior parietal gyrus* is situated between the inferior postcentral sulcus, the Sylvian fissure, and the horizontal limb of the parietal fissure. The convolution is subdivided by the upturned end of the Sylvian fissure and

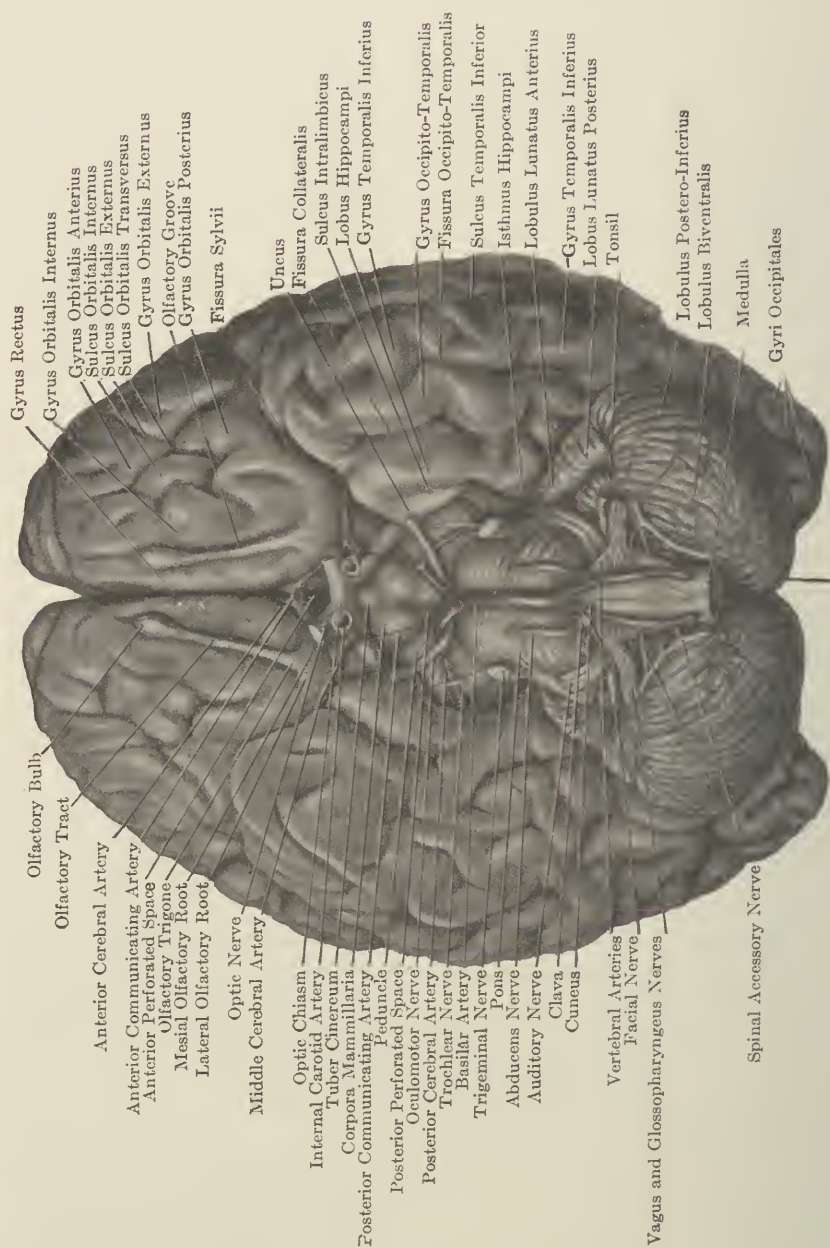


Fig. 454.—Norma basalis of the brain.

also by the terminations of the first and second temporal sulci. The extremities of these fissures determine the position of the *supramarginal*, the *angular* and the *postparietal gyri*.

The *supramarginal gyrus* passes around the upturned extremity of the Sylvian fissure.

The *angular gyrus* bears a similar relation to the upturned end of the superior temporal sulcus.

The *postparietal gyrus* curves above the extremity of the middle temporal sulcus.

The mesial surface of the parietal lobe comprises an irregular quadrate area extending from the mesial portion of the parieto-occipital sulcus to the Rolandic incisure. It is imperfectly limited below by the calloso-marginal sulcus and its continuation, the postlimbic fissure. The greater portion of this surface is embraced by the *quadrate lobule* or *precuneus*. This area is bounded in front by the ramus marginalis of the calloso-marginal fissure, and behind by the parieto-occipital sulcus.

The Occipital Lobe (*lobus occipitalis*). The occipital lobe is situated at the occipital pole of each hemisphere. It is pyramidal in shape and presents a mesial, lateral and basal surface. The mesial surface is separated by well defined fissures from the adjacent parietal and temporal lobes. In the apes the lateral surface is separated by a deep cleft, the *sulcus simiarum*, but in man this landmark is absent or represented by a smaller fissure, the *sulcus lunatus*. On the ventral surface there is no sulcus which serves as a line of demarcation between the occipital and temporal lobes. It is difficult, therefore, to determine the boundaries of the lobe on this surface. By some anatomists that portion of the hemisphere situated behind the plane of the parieto-occipital fissure is assigned to the occipital lobe. This includes the caudal portions of the parietal and temporal lobes. By others, however, the occipital lobe is regarded as having mesial and lateral surfaces but no ventral surface, the latter being assigned to the temporal lobe.

The mesial surface of the occipital lobe is separated by the parieto-occipital fissure from the precuneus and by the posterior division of the calcarine fissure from the gyrus lingualis of the temporal lobe. On the lateral surface it is bounded by the line drawn from the lateral division of the parieto-occipital fissure to the preoccipital notch. The mesial surface of the occipital lobe is occupied by a well defined gyrus termed the *cuneus*, or *cuneate lobule*. This lobule is triangular in shape and is bounded in front by the parieto-occipital fissure and below by the caudal division of the calcarine fissure. On the dorsal margin of the hemisphere it is continuous with the external surface where it is indented by two or three vertical sulci.

The lateral surface of the occipital lobe is divided by a transverse furrow, the *transverse occipital sulcus*, which appears most distinct in the fetus. Subsequently it joins the occipital portion of the intraparietal sulcus of which it appears to be the bifurcated caudal extremity. In apes, it is concealed by the occipital operculum, but on separating the convolutions bordering upon the sulcus simiarum it is seen on the anterior wall of the sulcus.

The lateral occipital sulcus extends obliquely backwards a short distance below the lateral end of the transverse occipital sulcus, toward the occipital pole of the hemisphere. The calcarine fissure not infrequently extends backward from the mesial surface of the hemisphere on to the lateral surface, where it bifurcates to form the *fissura extrema of Seitz*. This is visible when the hemisphere is viewed from its occipital pole.

The Temporal Lobe (*lobus temporalis*). The temporal lobe is somewhat pyramidal in shape, its cephalic extremity forming the temporal pole of the brain. It has a lateral, ventral and dorsal surface, the last being concealed within the fissure of Sylvius. The temporal pole forms the apex of the pyramid of the temporal lobe. It is free, directed forward, and lies beneath the orbital surface of the frontal lobe, from which it is separated by the horizontal limb of the Sylvian fissure. The lateral surface is bounded for two-thirds of its length by the lateral portion of the Sylvian fissure which separates it from the frontal and parietal lobes. At the caudal extremity of this fissure the lobe is continuous with the caudal portion of the parietal lobe and behind with the occipital lobe. On the ventral surface the lobe extends backward to the occipital pole and is bounded mesially by the calcarine fissure, the anterior division of the collateral fissure, and the incisura preoccipitalis, all of which separate it from the occipital and limbic lobes.

The lateral and ventral surfaces of the temporal lobe contain three sulci which have a cephalo-caudal direction. These are: (1) The *superior temporal sulcus*, which on account of its relation to the Sylvian fissure is sometimes referred to as the *parallel fissure*. It is constant in all primates. (2) The *middle temporal sulcus*, parallel to the superior and situated beneath it. It is, however, less constant in extent and direction, often being interrupted by one or more vertical annectant gyri. (3) The *inferior temporal sulcus*, seen upon the ventral surface of the lobe extending caudally toward the occipital pole. It is frequently interrupted near its cephalic and caudal extremities and sometimes about its middle by annectant gyri.

CONVOLUTIONS ON THE LATERAL AND VENTRAL SURFACES OF THE TEMPORAL LOBE. The convolutions on the lateral surface of the temporal lobe are three in number. The *superior temporal gyrus* is bounded above by the Sylvian fissure and below by the middle temporal sulcus. The *middle temporal gyrus* is separated from the superior temporal gyrus by the middle temporal fissure. The *inferior temporal gyrus* is continuous with the occipital lobe on the ventral surface of the brain. The fourth temporal gyrus, which is situated between the inferior temporal sulcus and the collateral fissure, appears on the ventral surface. It is sometimes spoken of as the *temporo-sphenoidal* or the *occipito-temporal convolution*. The caudal portion of this convolution is more sharply marked off by its bounding sulci. It is called the *fusiform lobule*, and has sometimes been described as part of the occipital lobe. Between the caudal divisions of the collateral and calcarine fissures is a fifth temporal gyrus, the *gyrus lingualis*. It is continuous in front with the hippocampal gyrus of the limbic lobe. Two deep annectant gyri connect it with the cuneus.

CONVOLUTIONS ON THE DORSAL SURFACE OF THE TEMPORAL LOBE. The dorsal, sometimes called the concealed or *operculo-insular* surface of the temporal lobe, is situated in such a manner as to form the lower boundary of the Sylvian fissure. It is of considerable extent, measuring 9 cm. from its cephalic to its dorsal extremity. At its caudal end its transverse diameter

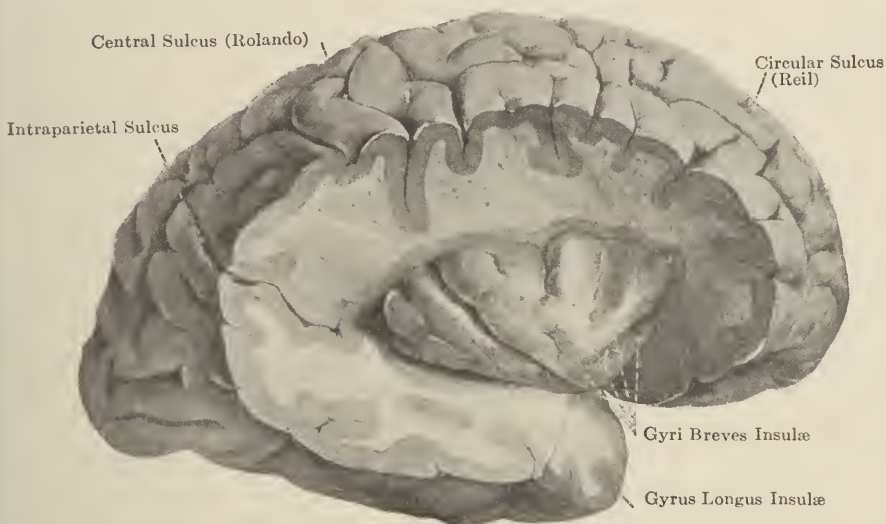


FIG. 455.—Right island, exposed, viewed from the right. The parts of the frontal, parietal and temporal lobes covering the island, *i.e.*, the opercula, have been removed by a cone-like section. (*Spalteholz.*)

is 3 or 4 cm. It becomes narrower as it passes forward until it reaches the cephalic extremity of the insula, where it again expands in a cephalic and mesial direction, reaching about 3 cm. in front of the insula; turning downward, it becomes continuous with the dorsal surface of the hippocampal convolution. It is divided into an opercular and an insular portion. The opercular portion is situated opposite the parietal and frontal opercula. The area lying below the parietal operculum consists of two or three gyri which have a direction mainly oblique and transverse. These convolutions cross this dorsal surface of the temporal lobe either obliquely, from without inward and forward, or directly transversely. They are the *transverse temporal gyri of Heschl*. The more cephalic of these gyri is the largest. In front of this gyrus the opercular surface rests against the orbital portion of the frontal operculum. It is marked by a number of short, shallow and irregular sulci, dividing it into a series of transverse temporal gyri. The insular surface directed mesially and dorsally toward the insula is often separated by a well-marked border from the opercular surface.

The Insula or Island of Reil (*lobus insularis*). This lobe is concealed in the human brain within the Sylvian fossa and may be brought to light only upon separating the opercula which bound the Sylvian fissure. In

order to obtain the best view of the insula it is necessary to excise the opercula which conceal it. It then appears as an irregular, three-sided pyramidal body with the apex directed ventro-cephalically and separated from the adjacent convolutions by a triangular sulcus, the *sulcus circularis* or *sulcus limitans insulæ*, which almost entirely surrounds it. At the apex, however, the insula is continuous with the anterior perforated space and thus with the orbital portion of the third frontal convolution and the dorsal surface of the head of the hippocampal convolution. This region is known as the *limen insulæ*.

SURFACES AND SULCI OF THE INSULA. Three surfaces are recognized in the island of Reil: the cephalic, dorsal and caudo-ventral surfaces. They are moulded against the corresponding portions of the several opercula. The cephalic surface lies in contact with the orbital and intermediate frontal opercula. The dorsal surface, which is the most extensive, is situated in relation with the fronto-parietal operculum. The caudo-ventral surface is pressed against the temporal operculum. The insula in general appears as a series of shallow sulci separating a series of convergent convolutions. These gyri are spread out like a fan the handle of which is situated at the apex where the island comes into relation with the anterior perforated space. One of the sulci is much deeper than the others and appears earlier. It is also more constant in the lower primates. This is the *sulcus centralis insulæ*. It serves to subdivide the insular lobe into two parts, a precentral and a post-central insular lobule. The precentral lobule of the insula consists of several short convolutions known as the *gyri breves*, which converge from the sulcus circularis insulæ toward the apex. These convergent gyri are usually three in number, an anterior, middle and posterior, being separated by secondary shallow sulci having the same general direction as the sulcus centralis insulæ. The most marked of these sulci, situated between the middle and posterior gyri breves, is the *sulcus precentralis insulæ*. A fourth small gyrus has been described lying deeply beneath the orbital operculum. This has been called the *gyrus brevis accessorius insulæ*.

The *postcentral lobule* (*gyrus longus insulæ* of *Giacomini*) is also subdivided by a longitudinal furrow, the *sulcus postcentralis insulæ*, into two parts, an anterior and a posterior gyrus. Its gray matter is continuous below with the tip of the hippocampal gyrus and laterally with that of the first temporal gyrus; above it is continuous with the gray matter of the parietal and temporal opercula.

The three principal furrows of the insula, sulcus centralis, sulcus precentralis and sulcus postcentralis, which radiate from the vallecule of Sylvius, have been compared with the three similarly radiating fissures on the lateral surface of the hemisphere; namely, the *central*, the *precentral* and the *post-central fissures*. They are, however, not direct continuations of these, inasmuch as they are interrupted by the sulcus circularis insulæ.

The Limbic Lobe or Archipallial Rhinencephalon (*lobus limbicus*). The limbic lobe constitutes the central or cortical portion of the rhinencephalon. The rhinencephalon itself is the olfactory portion of the endbrain. In the

lower vertebrates (fish) it is the chief element of the telencephalon, consisting of an olfactory bulb and an olfactory lobe which constitute the *primordial rhinencephalon*. In such forms as amphibia and reptiles, in which an olfactory cortex first makes its appearance as a primitive hippocampal formation, the primordial rhinencephalon is augmented by an archipallial rhinencephalon. In mammals this archipallial rhinencephalon is represented in a broad sense by the *limbic lobe*. The mammalian rhinencephalon, therefore, consists of a primordial (sometimes called peripheral) and an archipallial (often referred to as central) portion.

The primordial (peripheral) rhinencephalon consists of the anterior and posterior olfactory lobes.

The archipallial (central) rhinencephalon constitutes the limbic lobe.

The *grande lobe limbique* was originally described by Broca as consisting of the *gyrus callosus* (*gyrus cinguli*) and the *gyrus hippocampi*, which together form the *gyrus fornicatus*. The configuration of these two portions of the limbic lobe suggested to Broca a structure which formed a hilus (not unlike the hilus of the kidney) on the mesial surface of the hemisphere. Through this hilus various fasciculi pass inward to unite the hemisphere with the corresponding structure of the opposite side or to connect it with lower portions of the brain and central axis.

This is a region of the brain which has been extensively studied. To the parts of the limbic lobe already described by Broca, Schwalbe added other central portions of the mesial wall of the hemisphere, which include the lamina septi pellucidi and the fornix. Subsequent additions were made to this region, including the *gyrus fasciolaris*, *gyrus intralimbicus*, the *gyri Andreae Retzii*, and the *gyrus supracallosus*.

As now understood, the limbic lobe is composed of three concentrically arranged limbic (marginal) arches upon the mesial surface of the embryonic hemisphere in relation with the corpus callosum and third ventricle. The outermost of these arches is the *limbus corticalis* which represents the cortical portion of the rhinencephalon. From it the following parts are derived:

1. The *gyrus fornicatus*, which consists of the *gyrus cinguli*, the *isthmus hippocampi* and the *gyrus hippocampi*.

2. The *gyrus uncinatus*, *gyrus intralimbicus*, *gyrus ambiens* and *gyrus semilunaris*.

3. The *gyrus dentatus* and the band of *Giacomini*.

4. The *gyrus fasciolaris*.

5. The *gyrus supracallosus*, which includes the *indusium griseum*, *striae longitudinales mediales* (Lancisii) and *striae longitudinales laterales*.

6. The *gyri Andreae Retzii*.

The middle of the three limbic arches is the *limbus medullaris* which consists of:

1. The *fimbria*.

2. The *body of the fornix*.

3. The *anterior pillars of the fornix*.

4. The *septum pellucidum*.

The innermost of the three limbic arches is the *limbus chorioideus*, which consists of the lateral chorioid plexus.

The limbic lobe is bounded on its outer circumference by the callosal fissure above and the cephalic portion of the collateral and rhinal fissures below, while the less constant subparietal or postlimbic sulcus separates it from the parietal lobe. The cephalic division of the calcarine fissure projects into the limbic lobe just below the splenium.

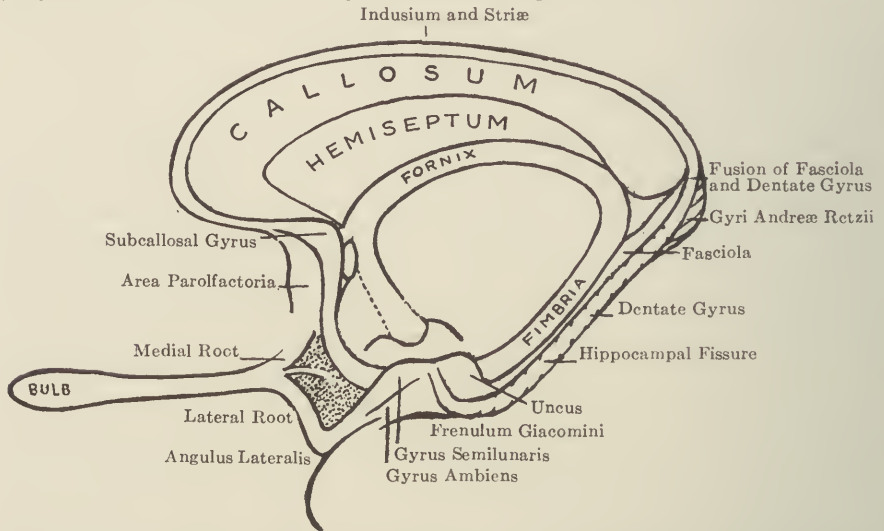


FIG. 456.—Schema showing the relations of the primordial and archipallial rhinencephalon. (Gray.)

The inner boundary of the lobe is formed by the fissura chorioidea, through which the chorioid plexus invaginates itself into the lateral ventricle. The *limbus corticalis* is bounded internally by the supracallosal and hippocampal fissures, and is separated from the *limbus medullaris* by the fimbrio-dentate fissure. At the splenium the fimbria and gyrus dentatus become widely separated, the dentate gyrus being prolonged around the splenium over the dorsal surface of the corpus callosum as the gyrus supracallosus, while the fimbria turns to pass forward in relation to the ventral surface of the corpus callosum where it becomes the body of the fornix.

CONVOLUTIONS AND FISSURES OF THE LIMBIC LOBE. The *limbus corticalis* of the limbic lobe consists of six distinct gyri:

1. The *gyrus fornicatus* is made up of the gyrus cinguli, gyrus hippocampi and isthmus hippocampi. The gyrus cinguli (callosus) is a large convolution situated between the marginal gyrus of the frontal lobe and the quadrate lobule of the parietal lobe above and the corpus callosum below. This convolution sweeps over the corpus callosum, beginning below the rostrum where it abuts upon the subcallosal gyrus. It ends a little below the level of the splenium, becoming continuous here with the caudal extremity of the hippocampal gyrus. Where it passes into this latter gyrus

it becomes narrow to form the *isthmus hippocampi*. It is separated from the corpus callosum by the supracallosal fissure.

The gyrus hippocampi is continuous caudally with the gyrus cinguli above and the lingual gyrus below. Passing forward it at first is situated between the hippocampal sulcus and the cephalic division of the collateral fissure. The hippocampal gyrus consists of an exposed portion visible upon the mesial surface of the brain, the *subiculum hippocampi*, and a sunken area of cortex in relation with the depths of the hippocampal fissure and the temporal horn of the lateral ventricle, the *cornu Ammonis*. The gyrus finally expands to form the caput gyri hippocampi and curves back in a hook-like process, the *uncus*.

2. The *gyrus uncinatus* (*uncus*) is situated on the dorsal aspect of the hippocampal gyrus above the end of the hippocampal fissure. The caput of the hippocampal gyrus does not reach the apex of the temporal lobe, being separated from it by the *incisura temporalis*. Upon its upper concealed surface there are two constant elevations, one of which is median in position, the *gyrus semilunaris*, and a lateral prominence, the *gyrus ambiens*. The caput gyri hippocampi is the cortical center of smell and corresponds to the lobus pyriformis of macrosomatic mammals.

The uncus is crossed at about its middle by a continuation of the gyrus dentatus, the *band of Giacomini*. The portion of the uncus above this band is the *gyrus intralimbicus*.

3. The *gyrus dentatus* (*fascia dentata Tarini*), a portion of the limbus corticalis, lies above the hippocampal gyrus concealed in the depths of the hippocampal fissure. It is a narrow convolution with a serrated or notched appearance along its free border, and from this fact it derives its name. Above and overlapping it is the fimbria, from which it is separated by a narrow sulcus, the *fimbrio-dentate sulcus*. The gyrus dentatus terminates ventrally in an attenuated and slightly elevated band, which crosses the exposed surface of the gyrus uncinatus. This is the *band of Giacomini*. It separates the *gyrus intralimbicus* from the *gyrus semilunaris*.

4. The *gyrus fasciolaris* is a small cylindrical strand of cortical substance situated between the gyrus dentatus and fimbria in the fimbrio-dentate sulcus. It is separated from the gyrus dentatus by a shallow groove, the *sulcus dentato-fasciolaris*, and is continuous over the dorsal surface of the splenium with the *supracallosal gyrus* or *indusium griseum*.

5. The *gyrus supracallosus* (*epicallosus of Retzius*) is situated upon the dorsal surface of the corpus callosum. It is continuous caudally with the gyrus fasciolaris and cephalically with the gyrus subcallosus. It consists of a thin atrophic lamina of gray matter, the *indusium griseum*, through which pass the *striae longitudinales mediales* and the *striae longitudinales laterales*.

6. The *gyri Andreae Retzii* represent two or three small and rudimentary callosal gyri. They are in relation with the mesial surface of the gyrus hippocampi immediately beneath the splenium of the corpus callosum, occupying the angle between the gyrus dentatus and the gyrus hippocampi. These gyri are not constant. Gustav Retzius gave them the name of his father who discovered them.

The *limbus medullaris* of the limbic lobe represents the medullary substance of this division of the brain, the arrangement of which produces an uninterrupted tract of fibers. For purposes of description, three parts are distinguished in the *limbus medullaris*:

1. The *fimbria hippocampi* is the white matter of the hemisphere which here comes to the surface along the margin of the dentate gyrus. It is continuous with the *alveus*, which covers the hippocampus within the lateral ventricle. The fimbria is formed of fibers which are continued into the body of the fornix. In the ventral direction it extends into the white matter of the uncus.

2. The *body of the fornix* contains a large fasciculus of fibers which unites the hippocampus with the olfactory lobe. This is the olfactory bundle of the cornu Ammonis. It is best developed in macrosmatic animals. Traced forward, it is found to enter and then leave the anterior pillars of the fornix and pass into the anterior commissure and thence extend in the subcallosal gyrus to the vallecule Sylvii. At this point the fasciculus divides into the *pars olfactoria*, which passes along the anterior circumference of the lamina perforata anterior to the inner root of the olfactory tract, and the *pars temporalis*, which passes along the caudal border of the anterior perforated space as a narrow band to end in the hippocampal gyrus. This is the *diagonal band of Broca*.

3. The *anterior pillars of the fornix* are the direct continuation of the fasciculi of fibers contained in the body of the fornix. They are described in detail on page 795.

The *lamina septi pellucidi*, which forms the mesial wall of the frontal horn of either lateral ventricle and with its fellow of the opposite side bounds the "fifth ventricle," also belongs to the *limbus medullaris*. It has been separated from the supracallosal portion of the limbic lobe by the development of the corpus callosum.

The *limbus chorioideus* is the innermost of the three limbic arches. It forms the chorioid plexus of the lateral ventricle, which invaginates itself through the chorioid fissure.

THE PRIMORDIAL RHINENCEPHALON. This primitive part of the rhinencephalon is rudimentary in many mammals and in man. It includes the bulbus olfactorius, the tractus olfactorius, the trigonum olfactorium, the area parolfactoria of Broca, the substantia perforata anterior, the gyrus subcallosus and the diagonal band of Broca. All of these structures are situated upon the basal surface of the brain. The parolfactory area occupies a small surface on the mesial aspect of the hemisphere.

The *olfactory bulb* is an elongated, oval swelling 10 mm. long, 4 mm. wide and 2.5 mm. thick. It is continuous caudally with the olfactory tract and is lodged in the olfactory sulcus. The bulb rests upon the cribriform plate of the ethmoid bone, through the apertures of which the bundles of the olfactory nerve, *fila olfactoria*, ascend from the nasal mucous membrane. The bulb consists of a stratum of olfactory fibers forming a narrow medullary layer, a stratum of mitral cells in which are contained the olfactory glomeruli

consisting of the intricate intertwining of the axones ascending from the olfactory cells, together with dendrites of the mitral cells. The third stratum consists of the axones of the mitral and other nerve cells which enter into the formation of the olfactory tract.

The *olfactory tract* is a narrow band consisting chiefly of white matter which extends from the olfactory bulb to the trigonum olfactorium. It measures 2 cm. in length and 2.5 mm. in width, and is broadest at its caudal extremity, from which the olfactory roots diverge. The ventral surface is flat, the dorsal surface is ridged and rests in the olfactory sulcus. The structure of the olfactory tract indicates the rudimentary condition of this part in man. It contains no central lumen, as in the case of many of the lower mammals. It is made up of a stratum of nerve fibers having a longitudinal course, internal to which is a gelatinous stratum representing the residuum of the ventricular cavity seen in lower animals. Mesial to this substance is a dorsal stratum of gray matter. The olfactory striæ or roots of the olfactory tract are usually two in number, a mesial and a lateral root. In certain instances there are additional intermediate roots indicated by faint strands of fibers. The mesial root turns sharply inward, passes over the inner margin of the olfactory trigone and disappears on the mesial surface of the hemisphere. It ends partly in the supracallosal and partly in the subcallosal gyri. The lateral root passes obliquely along the cephalo-lateral margin of the anterior perforated space and usually disappears in the vallecula Sylvii to end in the uncus.

The *trigonum olfactorium* is a triangular convex area situated between the two roots of the olfactory tract and separated behind from the anterior perforated space by a short groove, the sulcus parolfactorius posterior.

The *area parolfactoria*, or *field of Broca*, is a small curved tract upon the mesial surface of the hemisphere cephalo-ventral to the gyrus subcallosus. It extends from the rostrum of the corpus callosum to the anterior perforated space. The area is bounded by the sulcus parolfactorius anterior in front, and the sulcus parolfactorius posterior behind. It is connected with the superior frontal gyrus in front and above with the gyrus callosus. It is continuous below with the inner part of the trigonum olfactorium.

The *substantia perforata anterior* or anterior perforated space is an irregular triangular region caudal to the trigonum olfactorium and separated from it by the sulcus parolfactorius posterior. It is situated in front of the optic chiasm. Its inner portion is narrow and extends to a point between the mesial root of the olfactory tract and the lower extremity of the subcallosal gyrus. Its ventral portion extends into the floor of the vallecula Sylvii and reaches the deeper part of the uncus. It takes its name from the large number of small apertures in it for the transmission of the perforating branches of the antero-mesial and antero-lateral ganglionic groups of basal arteries. It consists of a thin lamina of gray matter containing groups of nerve cells some of which constitute the nuclei of primary centers in the olfactory pathway connecting the olfactory lobe with the secondary cortical olfactory centers.

The *gyrus subcallosus* is a narrow band seen on the mesial surface of the

hemisphere immediately below the rostrum of the corpus callosum. It is situated caudal to the area parolfactoria from which it is separated by the sulcus parolfactorius posterior.

The *diagonal band of Broca* is an obliquely directed ribbon-like tract which at times may be distinguished along the inner margin of the anterior perforated space. In front it is continuous with the subcallosal gyrus and caudally passes from the optic tract toward the cephalic extremity of the hippocampal convolution.

Summary of the Parts Entering into the Formation of the Rhinencephalon. In mammals the rhinencephalon consists of:

1. The primordial rhinencephalon.

2. The archipallial rhinencephalon.

The primordial rhinencephalon comprises the following parts:

1. The olfactory bulb.

2. The olfactory tract.

3. The olfactory trigone.

4. The parolfactory area.

} The anterior olfactory lobe.

5. The anterior perforated substance.

6. The gyrus subcallosus.

7. The diagonal band of Broca.

} The posterior olfactory lobe.

The archipallial rhinencephalon comprises constituents derived from three limbic arches: (1) The limbus corticalis; (2) the limbus medullaris, and (3) the limbus chorioideus.

The derivatives of the limbus corticalis are:

1. The gyrus fornicatus, including the gyrus cinguli, the gyrus hippocampi and the isthmus hippocampi.

2. The gyrus uncinatus, gyrus intralimbicus, gyrus semilunaris and gyrus ambiens.

3. The gyrus dentatus and band of Giacomini.

4. The gyrus fasciolaris.

5. The gyrus supracallosus, including the indusium griseum, striæ longitudinales mediales and laterales.

6. The gyri Andreae Retzii.

The derivatives of the limbus medullaris are:

1. The fimbria.

2. The body of the fornix.

3. The anterior pillars of the fornix.

4. The lamina septi pellucidi.

The derivative of the limbus chorioideus is the chorioid plexus of the lateral ventricle.

CHAPTER XXXVII

THE ENDBRAIN

DEVELOPMENT AND COMPARATIVE MORPHOLOGY OF THE CEREBRAL HEMISPHERES

The Two Principal Elements of the Prosencephalon. The early development of the neural folds resulting in the formation of the primitive encephalic vesicles has already been discussed on page 27. The process of differentiation which continues after the primitive forebrain (prosencephalon) has been formed, depends primarily upon the differentiation of the optic evagination. The second element of importance is a relatively narrow strip of prosencephalic tissue which almost completely surrounds the evagination of the eye, the *ectoptic zone of Schulte*. The further progress of the optic evagination results in the development of the retinal portion of the eye and the optic stalk which gives rise to the optic nerve, chiasm and tract. This derivative of the forebrain becomes gradually reduced in size while the ectoptic zone increases in prominence. It is to the evolution of this later element, the ectoptic zone, that attention is now especially directed.

Differentiation of the Ectoptic Zone of Schulte. The region of the primitive forebrain which surrounds the optic evagination soon begins to show a topographic differentiation into three discrete areas. These areas are: (1) The dorsal portion of the ectoptic zone, which ultimately gives rise to the thalamencephalon and metathalamus; (2) the ventral portion of the ectoptic zone, from which the hypothalamus is derived, and (3) the cephalic portion of the ectoptic zone, from which the endbrain takes origin.

In its inception the telencephalon has little to distinguish it from the diencephalon. It contains the continuation of the same cavity which is bounded by the interbrain, and has the appearance of a single median evagination extending forward in front of the optic stalk and the thalamencephalon. The neural wall which surrounds it is at first relatively thin, consisting of five or six layers of cells which present the three layers typical of the primitive tube. The mantle layer and marginal zone are less clearly marked. The most cephalic portion of the telencephalic vesicle consists of an attenuated plate which represents the line of closure at the neuropore. This thin limiting membrane at the cephalic extremity of the endbrain is the *lamina terminalis*.

Development of the Lateral Telencephalic Evaginations, the Hemispheres. At an early period the part of the ectoptic zone destined to participate in the formation of the endbrain is separated from the dorsal portion of this zone by a faint oblique groove which appears on either lateral surface. This groove extends obliquely from above downward and backward, and

is the *thalamo-telencephalic sulcus*. It serves as a caudal boundary of the primitive endbrain, the ventral boundary of which is formed by the junction of the two optic stalks along the ventral surface of the forebrain. In its earliest form the telencephalon is a single evagination. At a relatively early stage, however, two evaginations make their appearance, one on either side, and begin to grow rapidly. As each of these lateral diverticula increases in size it becomes demarcated from the original median vesicle of the endbrain by a slight groove, the *septal sulcus*, which runs obliquely from before backward. The two septal sulci produce a differentiation which appears largely on the dorsal surface of the endbrain and separates a median unpaired portion of the endbrain from two lateral diverticula. The lateral diverticula become the hemispheres and together constitute the *hemispherium*, while the median unpaired portion constitutes the *aula* which contains the cephalic portion of the third ventricle. At first the communication between the aula and the two hemispheres is an ample one. It gradually becomes reduced in size, first by the downward ingrowth of a portion of the hemispherical evagination along the line of the septal sulcus which forms the *septum transversum*; second by a marked increase in the thickness of the floor of each hemispherical evagination, which results in the formation of the *corpus striatum*. While these two elements increase in size the hemispherical vesicle is also developing rapidly and soon begins to overshadow the aula. A simultaneous increase in the size of the septum transversum and corpus striatum reduces the formerly large opening between the aula and the hemisphere until finally it becomes a small aperture. This aperture is the *foramen of Monro*. It establishes communication between the cavity of the third ventricle and the ventricular chambers contained in the hemispheres.

As growth proceeds, the aula is relatively more and more reduced in size by the rapid expansion of the hemispheres which extend forward, backward, upward and downward. In their forward growth they tend to approximate each other upon their mesial surfaces and thus overgrow not only the unpaired medial portion of the endbrain, but also the superjacent structures constituting the thalamus and metathalamus. The evagination resulting in the formation of the hemispheres involves only that part of the neural wall immediately caudal to the lamina terminalis and ventral to a portion which now may be recognized as occupying the position of a roof-plate.

The lamina terminalis persists into adult life as the cephalic boundary of the third ventricle, while the roof-plate of the aula gives rise in the early stages in man to a slight elevation which seems to represent an attempt at formation of the paraphysis. This attempt, however, is abortive. The more caudal portion of the roof-plate of the aula does, however, become involved in the formation of the chorioid plexus which extends through the foramen of Monro and forms part of the chorioidal gland system in the body of the lateral ventricle.

Development of the Corpus Striatum. One of the chief features of the development of this part of the brain is dependent upon the marked expansion of the hemispheres. From the outset, the corpus striatum is directly

continuous with the thalamic plate of the diencephalon. In many respects its development resembles that of the thalamus with which it becomes intimately associated, although the two structures are separated from each other in the early stages by a deep groove, and later by the tenia semi-circularis. The striate body consists of a ridge which is recognizable at about the first week as a triangular elevation in the ventro-lateral aspect of the hemispherium lateral to the optic recess. In a somewhat later stage this elevation projects inward immediately in front of the spacious foramen of Monro. Upon the lateral surface of the pallium this thickness corresponds to the small depression which indicates the beginning of the Sylvian fossa. This close association, in fact, between the surface of the pallium and the corpus striatum which retards the expansion of the brain wall in this area, leads to the formation of the Sylvian fossa and the development of the opercula of the insula. The effect of the fixation of the Sylvian fossa to the

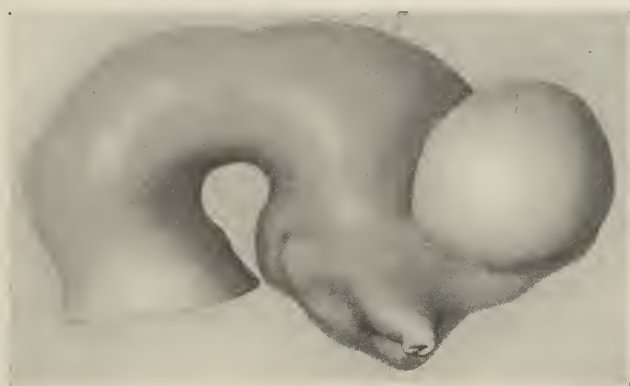


FIG. 457.—Model of the external surface of the forebrain of a 10 mm. human embryo showing the beginning of the superposition of the forebrain on the interbrain, and the delimitation of the rhinencephalon. (*His.*)

rapidly growing area within the interior of the brain vesicle seems to bring about a rapid expansion of the pallial wall in all directions, while the area of the fossa itself undergoes a comparatively slight degree of expansion. As the brain wall thickens in the development of the corpus striatum, this body projects into the ventricle of the endbrain. The thickening at first involves the ependymal zone, which undergoes rapid growth. Gradually, however, a mantle layer is formed which furnishes the neuroblasts from which the corpus striatum is formed. Many strands of fibers extending to and from the thalamus become arranged in a well demarcated lamina serving to subdivide the striate body into the globus pallidus, putamen and caudate nucleus; the latter division between the putamen and the caudate nucleus is determined by the subsequent ingrowth of the fibers which form the internal capsule. The arrangement of the capsular fibers in man and the higher mammals follows an exact pattern, giving the capsule the anatomic divisions to be described later. In some mammals, the invasion of the

corpus striatum by the fibers of the projection system is much less discrete. These fibers pass through the striate body in a diffuse manner so that an actual capsule is indistinct or entirely absent.

During the period in which the area of the pallium situated in front of and behind the Sylvian fossa is rapidly expanding, this fossa, as has already been pointed out, remains more or less stationary and acts, as it were, in the manner of a pivotal point about which further growth takes place. The result of the surrounding pallial expansion is especially marked in a curve formed in the lateral wall of the endbrain vesicle. This curve ultimately differentiates an area which sweeps downward then forward to form the temporal lobe, while its caudal extremity becomes the occipital lobe. Its cephalic



FIG. 458.—Model of the internal surface of the forebrain of a 10 mm. human embryo, showing the wide-open foramen of Monro, and the anterior and posterior olfactory lobes. (*His.*)

portion forms the frontal lobe. This arcuate growth in the lateral wall of the endbrain vesicle has its effect upon the shape of the telencephalic ventricle which now presents an anterior and a descending horn. It also has its influence upon a portion of the corpus striatum, particularly that part which lies closest to the lateral wall of the hemisphere, the nucleus caudatus. Following the general sweep backward, downward and forward, in the expansion of the pallial wall, a portion of the caudate nucleus is drawn out to form the body of that nucleus, while its tail is still further extended and deflected downward into the descending horn of the ventricle. The line of demarcation between thalamus and corpus striatum, at first a deep groove, is still maintained. It appears in the form of the *tenia semicircularis* which separates the body and tail of the caudate nucleus from the optic thalamus.

Divisions of the Corpus Striatum. The area determined by the development of the corpus striatum in the ventro-lateral aspect of the pallial wall, is called the *stalk of the hemisphere*. In this region, according to some authorities, a fusion takes place between the corpus striatum and the cephalic portion of the thalamus. According to another view, the increase in the size of this

region is due to a simple thickening of the walls which results in the production of the groove intervening between the thalamus and striate body. Whichever process underlies this development the effect is similar. Apposition and fusion are accomplished by massive connections consisting of fibers which join the hemispheres to the thalamus. One result of this process of approximation and thickening in the region of the hemispherical stalk, is the reduction of the foramen of Monro to a small, slit-like orifice. The growth of the connecting bundles of fibers between the thalamus and striate body continues until the axones are assembled to form the laminæ which divide the lenticular nucleus into its two constituent parts, the *globus pallidus* and the *putamen*. The invasion by the projection fibers of the pal-

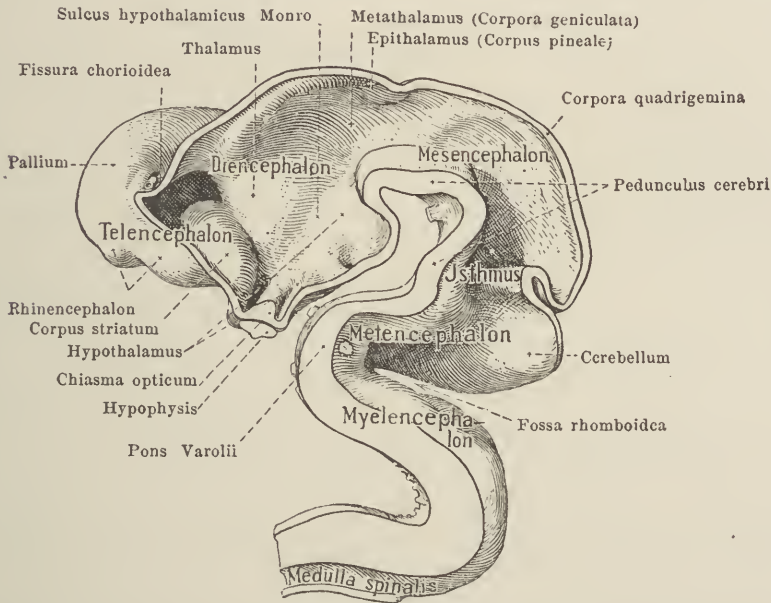


FIG. 459.—Lateral view of the ventricular system of the human embryo brain. (*His.*)

lium eventually separates the *caudate nucleus* from the *lenticular nucleus*. In this manner the several divisions of the corpus striatum are established.

Neuroblasts from the mantle layer proliferate rapidly and give rise to the large motor cells in the *globus pallidus*. Many of these neuroblasts migrate beyond these limits into the putamen. A large number of young nerve-cells arising in the mantle layer make their way into the putamen and caudate nucleus, where they become differentiated as small and medium-sized cells. The putamen and the caudate nucleus thus present a certain number of large motor elements, but the dominant elements in both of these divisions of the corpus striatum are the small and medium-sized cells whose axones form internuclear connections but do not participate in the formation of the projection system of the corpus striatum.

At the end of the fifth month the relation and form of the corpus striatum

are essentially those of the adult. The internal capsule is now discernible. It contains fibers connecting the thalamus with the corpus striatum and pallium, acoustic fibers from the metathalamus to the pallium and projection fibers from the pallium.

The Rhinencephalon. The rhinencephalon is represented by a primordial and a pallial portion of the cerebral hemisphere, both of which are connected with olfactory functions. The primordial rhinencephalon, consisting of the anterior and posterior olfactory lobes, makes its appearance in embryos at the sixth week. It is an elongated area not well demarcated from the inner surface of the pallium. The olfactory lobe is subdivided by a transverse groove into a cephalic and caudal portion. From the cephalic division are developed the olfactory bulb, the olfactory tract, the trigonum olfactorium, the olfactory roots and the parolfactory area. From the caudal division are developed the anterior perforated space, the gyrus subcallosus and the diagonal band of Broca. These structures are relatively rudimentary in man. A continuation of the lateral ventricle through the olfactory tract into the bulb is well defined in the early embryonic stages. This communication gradually disappears. In adult man neither the olfactory bulb nor the tract contains any remnant of the ventricular chamber.

The *pallial rhinencephalon* comprises the structures of the limbic lobe. With the development of the corpus callosum and its gradual encroachment upon the cortex of the hippocampal formation, a portion of the pallium becomes rudimentary in man and is reduced to a thin veil of gray matter situated upon the dorsum of the corpus callosum. The portion of the pallium entering into the formation of the rhinencephalon constitutes the *archipallium*, in contradistinction to that portion of cerebral cortex not concerned in gustatory or olfactory sense which constitutes the *neopallium*. The archipallium consists of an extension of the basal area of the endbrain and forms the mesial margin of the cortex bounding the dorsal border of the chorioidal fissure. It differs from the olfactory lobe in that its cells are arranged in the layers characteristic of the cerebral cortex. The mesial portion of the pallial wall in the area destined to participate in the hippocampal formation, shows three distinct zones at the beginning of the second month in the human embryo. Each zone, in consequence of the ventro-cephalic curvature developing in the brain wall, presents itself as an arch. The most dorsal of this series of three parallel arches is the thickest, because it implicates the entire depth of the pallium at this stage. For this reason it is known as the *limbus corticalis*. Immediately ventral to this limbic arch and parallel to it, is a region in which the pallial wall has become attenuated, contains no cellular elements, and is composed exclusively of nerve fibers extending backward and forward in a parallel line. This is the *limbus medullaris* which constitutes the fimbria and fornix in the adult. Immediately ventral to the limbus medullaris the brain wall becomes still further attenuated, being represented by ependyma alone. This region which undergoes an invagination into the body and the descending horn of the lateral ventricle, is the *limbus chorioideus*. The invagination soon becomes deep and results in the formation of a

double-layered ependymal fold, the *chorioid fold*, which lies above the body of the corpus striatum in the lateral ventricle. Subsequently the limbus chorioideus is invaded by mesenchymal elements which pass between the two folds and in this way form the chorioid plexus of the lateral ventricle. The invagination of the limbus chorioideus produces the *chorioid fissure* which gradually becomes elongated and somewhat arched, so that its caudal extremity is progressively carried downward and forward into the temporal horn of the lateral ventricle.

In the third month of development a shallow sulcus appears in the limbus corticalis parallel to the chorioid fissure. This is the *posterior arcuate fissure*. At first it does not extend so far forward as the chorioid fissure, but has a greater caudal extension, in this region arching downward into the temporal lobe at about the caudal extremity of the chorioid fissure. The posterior arcuate fissure is a primary or total fissure involving the whole brain wall and thus producing a prominence on the inner surface of the ventricle. The caudal portion of this prominence persists in the adult without further change. The fissure becomes the adult hippocampal fissure, which separates the gyrus dentatus from the subiculum of the gyrus hippocampi. The inverted portion of the cortex produced by the invagination of the hippocampal fissure forms a prominence in the lateral ventricle known as the cornu Ammonis. The chorioid plexus, as it extends upward, presents a thickening in the limbus medullaris called the *tenia chorioidea*. A similar thickening below is the *lamina infrachorioidea* or *lamina affixa*, by means of which the mesial surfaces of the brain wall at the junction of the corpus striatum and optic thalamus are fused.

The caudal portion of the hippocampal formation comes into relation with the descending horn of the lateral ventricle and gives rise to the several complicated structures of this region. The limbus corticalis, which consists of elements ultimately giving rise to cerebral cortex, becomes invaginated along the line of the hippocampal fissure to form the *subiculum of the hippocampal gyrus* and the *gyrus dentatus*. The limbus medullaris forms the fimbria and thus gives rise to the major projection system of the hippocampal formation. The limbus chorioideus gives rise to the chorioid plexus of the lateral ventricle, and the line of this invagination forms the chorioid fissure. These changes are confined to the more caudal portion of the hippocampal formation. The cephalic portion of this structure undergoes modifications of an entirely different type. While the development of the caudal portion of the hippocampal formation is dependent upon the invagination of the three limbic areas in relation with the chorioid and hippocampal fissures, its cephalic portion, on the other hand, is altered principally as the result of growth of commissural fibers in this region. Some of these fibers connect the hippocampus of the two sides in the form of the *commissura fornicis*. The majority of the commissural fibers are contained in the corpus callosum and connect the neopallial areas of the two hemispheres.

The first commissural fibers, according to one view, appear in the dorsal portion of the lamina terminalis and subsequently extend with the expan-

sion of the corpus callosum. These commissural fibers are confined to the original wall connecting the two hemispheres. According to another view, there is a secondary fusion of the mesial hemispherical wall and in these areas of fusion the fibers cross from one side to the other. The first fibers appear during the third month and form a small band in the upper portion of the lamina terminalis. These fibers come partly from the limbus corticalis and are therefore commissural fibers of the hippocampal formation.

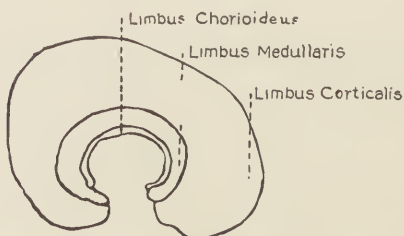


FIG. 460.—Rhinencephalic zones.

The development of the corpus callosum itself occurs through the region occupied by the limbus corticalis. As the callosal fibers increase in number, this limbus undergoes gradual changes, giving way before the advance of the corpus callosum. The limbus corticalis is in this way reduced to a vestigial structure represented by the indusium griseum and striæ longitudinales mediales and laterales on the dorsal surface of the corpus callosum. The part of the limbus medullaris ventral to the corpus callosum becomes the body of the fornix, and its continuation forward becomes the anterior pillars of the fornix.

DERIVATIVES OF THE THREE LIMBIC AREAS OF THE ARCHIPALLIUM. The following structures are derived from the limbus corticalis in its supracallosal portion: (1) The gyrus cinguli; (2) the vestigial cortex covering the dorsum of the corpus callosum, that is, the indusium griseum and striæ longitudinales.

The derivatives from the infracallosal portion of the limbus corticalis are: (1) The gyrus hippocampus; (2) the gyrus dentatus and several lesser gyri in this region.

From the limbus medullaris are derived: (1) The fimbria; (2) the body of the fornix; (3) the anterior pillars of the fornix, and (4) the septum pellucidum.

From the limbus chorioideus are derived: (1) The tenia fornicis; (2) the chorioid plexus, and (3) the lamina affixa.

Fibers from the gyrus hippocampi to the fimbria pass forward into the body of the fornix. These fibers come into relation with the lamina terminalis, form the anterior pillars of the fornix and from this point pass in a position caudal to the anterior commissure to reach the mammillary region. In their course they are joined by fibers from the dorsal surface of the corpus callosum. These fibers constitute the *fornix longus* of *Forel*, which is formed by fibers from the vestigial hippocampal formation situated upon the dorsum of the corpus callosum. Many of these also pass in front of the anterior commissure to the rhinencephalon. The triangular mesial area called the *septum pellucidum*, which is included between the corpus callosum and fornix, in all probability represents a portion of the lamina terminalis; it constitutes the "commissural bed" of the endbrain. The septum pellucidum on the right coming into close approximation with the corresponding structure on the left, forms a dead space, the so-called *fifth ventricle* or *ventricle of Verga*.

The Neopallium. The hippocampal formation represents the older portion of the pallium known as the archipallium. It is concerned with olfactory function, being for the most part the center for the reception and elaboration of olfactory impulses. The remaining portion of the pallial wall of the brain constitutes the neopallium. The further development of the neopallium results from the extension caudally of the brain walls so that they overlap

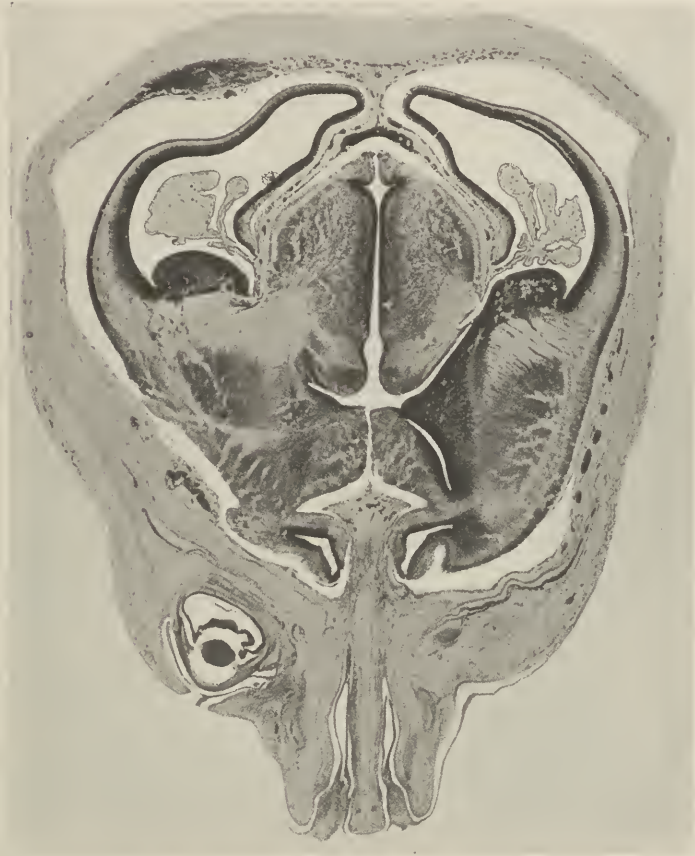


FIG. 461.—Cross section through the forebrain of a human embryo of the third month.

The section shows the indented form of the anterior olfactory cavity. The cavities of the olfactory bulb and of the trigonum are separated from each other by a lateral fold. The posterior olfactory cavity shows only on the right side—a narrow cleft on the point of separating from the lateral ventricle. On the left side, the posterior olfactory cavity no longer appears in the section. (*His.*)

the greater portion of the brain-stem and finally reach a position in relation with the tentorium cerebelli which separates them from the cerebellum. The occipital lobe in the course of this extension carries with it a cavity which becomes the occipital horn of the lateral ventricle. In the growth of the various portions of the hemisphere the neopallial surface is unequal, a fact which results in the production of folds separated by fissures. The folds are the

convolutions or gyri and the fissures are the cerebral sulci. The process of folding is in all probability in the interest of multiplying as much as possible the cell-containing substance of the brain. The gray matter, inasmuch as it contains fibers as well as cells, is spread out in a comparatively thin layer in order to make easier the processes of associative correlations. The position of these folds is partly determined by local histological differentiation. Some of the more important and earliest of the fissures and convolutions require special description.

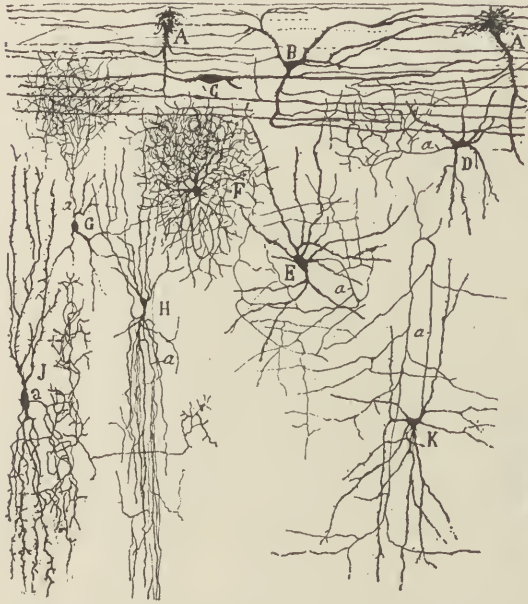


FIG. 462.—Superficial region of the motor cortex; one month old infant. Golgi's method. (Cajal.)

A, B, C—Horizontal cells of plexiform layer. D, E, F—Cells with short axis cylinders of the second layer, or small pyramidal cells. G—Cell with axis cylinder ascending to the first layer. H, J—Cells with double brush protoplasm. K—Large cell with short axis cylinder of the third layer. a—Axis cylinder.



FIG. 463.—The appearance of the cones of growth in the neuroblasts. (Cajal.)

A—According to the method of silver nitrate reduction. B—According to the method of Golgi. a—Bipolar cell, b—Nucleus. c—Cone of growth. E.

The Sylvian Fossa. Among the earliest evidences of convolution upon the surface of the neopallium is a fossa or depression on the lateral surface of each hemisphere, in close relation mesially with the corpus striatum. This depression is the fossa of Sylvius which subsequently becomes the *island of Reil (insula)*. The region destined to differentiate as the insula does not grow so rapidly as the parts surrounding it and is later overlapped by the frontal, parietal and temporal opercula. As the opercula form they tend to approximate each other and thus more and more obscure from view the island of Reil. The several opercula in relation with the Sylvian fossa approach each other so closely that they ultimately form the boundaries of the fissure of Sylvius. The temporal and fronto-parietal opercula make their appearance at the end of the fifth month. The temporal operculum grows more rapidly

at first, but later the fronto-parietal extends downward and changes the direction of the Sylvian fissure from oblique to almost horizontal. The development of the frontal lobe leads to another overlapping of the insula. The orbital and frontal opercula are not in apposition until the end of the first year.

At the end of the third fetal month the calcarine fissure makes its appearance and produces upon the mesial surface of the occipital horn of the ventricle an eminence known as the *calcar avis*.

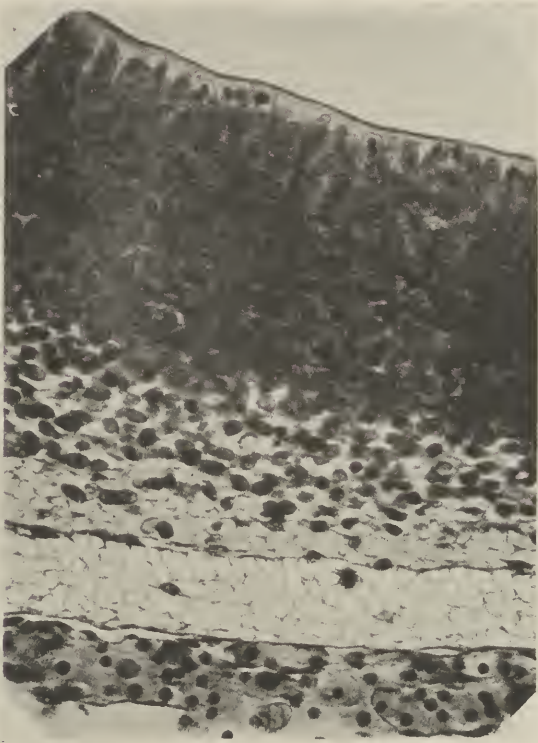


FIG. 464.—Cross section of the hemispherical wall of a human embryo of 16 mm. The mantle layer is beginning to separate from the nuclear layer. There is as yet no cortical layer. The marginal layer is plainly shown. External to the marginal layer is a zone more free from nuclei which later lodges the pyramidal cells. Next to this zone appears the lamina cribrosa or marginal velum, and beneath the pia is a layer almost destitute of nuclei which is the marginal layer and contains only a few neuroglial cells. The marginal layer is limited externally by the membrana limitans gliæ. (*His.*)

At the beginning of the fourth fetal month the *parieto-occipital fissure* unites with the calcarine fissure and thus delimits the *cuneus*. At the beginning of the sixth or seventh month the parieto-occipital fissure reaches the superior border of the hemisphere which it incises. At the beginning of the sixth month the *fissure of Rolando* makes its appearance.

Histogenesis of the Walls of the Neopallium. The wall of the hemisphere in the neopallial region is relatively undifferentiated up to the end of the second month. An increase in thickness becomes noticeable at this time but is not uniform in all regions. The increase is more advanced in the basal portion of the brain wall adjoining the corpus striatum. From this point it gradually extends toward the mesial line over the entire pallium. The thickness of the neopallial wall in embryos of six weeks to fetuses of four months, together with the measurements in each case, are given in the accompanying table.

TABLE SHOWING THICKNESS OF HEMISPHERAL WALL AND ITS CONSTITUENT LAYERS IN HUMAN EMBRYOS FROM THE SIXTH WEEK TO FETUSES OF THE FOURTH MONTH, COMPILED FROM MEASUREMENTS GIVEN BY HIS, 1904.

Approximate age and size of embryo	6 weeks 16 mm.	8 weeks 22 mm.	10 weeks 46 mm.	12 weeks 50 mm.	14 weeks 60 mm.	16 weeks 120 mm.
Total thickness.....	.145	.5	.6	.8	1.1	4.
Ependymal zone.....						.2
Mantle zone	.085	.16	.15	.15	.17	
(a) Nuclear portion						1.6
(b) Sparsely nucleated portion.....	.035	.25	.34	.41	.65	1.4
Marginal zone.....						
(a) Pyramidal layer.....		.06	.085	.2	.24	.8
(b) Non-nuclear marginal layer.....	.025	.03	.025	.04	.04	

In the early histogenic development of the pallial wall the usual differentiation of the ependymal, mantle and marginal layers occurs as elsewhere in the neuraxis. This differentiation may be considered as the common or ground plan of histogenesis in the central nervous system. In the next stage, however, there is a marked difference in the development which characterizes the pallium from that of the rest of the neural tube. This stage consists of the further migration outward of neuroblasts and their accumulation under the marginal layer where they form, at the beginning of the third month in the human embryo, a definite layer of closely crowded cells, the inception of the cerebral cortex. Subsequent migrations of neuroblasts add further to this layer. At about this time the fibers of the thalamic radiation appear in the neopallial wall and proceed toward the cortical layer. This marks the beginning of the medullary substance which by later myelination becomes the white matter of the hemisphere. Fibers from the lateral geniculate body and pulvinar proceed inward to the occipital region. Fibers from the mesial geniculate body are grouped together into a radiation in the temporal region; while others from the ventro-lateral thalamic nuclei, forming the continuation of the mesial fillet, pass outward to the future post-central area. All of these fibers collectively constitute the afferent projection system. Axones from the neuroblasts of the cortical layer grow inward toward the corpus striatum and enter the medullary layer to form the *centrum ovale* and the *corona radiata*.

The migration of neuroblasts is most active during the third month, but continues well into the fourth month. In the third month there is formed in the marginal zone a well developed cortical layer. The neuroblasts appear to be wandering outward in the direction of this stratum. The marginal zone becomes much broader and is subdivided into an inner nuclear portion consisting of neuroblasts and spongioblasts, and an outer, intermediate layer which has but few cells owing to the marked invasion of fibers from the internal capsule. A schematic representation of the neopallial wall at this period is shown in Figure 465. The figure shows the spongioblastic framework and the differentiation of several layers of nuclei representing neuroglial cells. At the right are wandering neuroblasts coming into a radial position to form the cortex. Passing outward they make their way through the meshwork of the neuroglia. The larger pyramidal elements are usually bipolar at this period. The ectal processes of the cells become the apical dendrites, while the slender central processes become the axones. The development of the basal and lateral dendrites in the attainment of adult characters of the neurone occurs in a later stage. The neopallial wall remains relatively thin and the ventricular chamber large until the fourth month. At this time the wall rapidly thickens, owing mainly to the increase in fibers in the intermediate layer. Cross section through the brain wall in this stage shows that it consists of four concentric layers: (1) The cortical layer; (2) the intermediate layer, made up of nerve fibers; (3) the internal layer, consisting of four concentric zones which are (a) the outer transitional layer, (b) the outer striated layer, (c) the inner transitional layer, (d) the inner striated layer; (4) the ependymal matrix. The ependyma does not seem to be so active at this time as previously, although it still gives off cells to form the cortical layer. At the end of the sixth or the beginning of the seventh month differentiation and grouping of the nerve cells has begun, and soon results in the formation of the six layers of the cortex. These layers are:



FIG. 465.—Schematization of the structure of the hemispherical wall in a fetus of the 3d month, showing on the left the neuroglial frame-work, and on the right the neuroblasts and nerve fibers. (*His.*)

1. The zonal layer (marginal plexiform layer of the adult).
 2. The external granular layer (layer of small pyramidal cells in the adult).
 3. The pyramidal layer (external layer of large pyramidal cells in the adult).
 4. Internal granular layer (stellate layer of the adult).
 5. Ganglionic layer (layer of internal large pyramidal cells in the adult).
 6. Multiform layer (fusiform and polymorphous layer in the adult).
- Modifications in the size and, to some degree, in the arrangement of layers of the cortex result in differentiation of the various histological areas of the adult cortex.



FIG. 466.—Neuroglia of the superficial layers of the brain; two months old infant. Golgi's method. (Cajal.)

A, B, C, D—Neuroglial cells of the plexiform layer. *E, F, G, H*—Neuroglial cells of the second and third layers. *I, J*—Neuroglial cells with vascular pedicles. *V*—Blood vessel.

In the calcarine area of the occipital lobe, in the sixth month, the internal granular layer differentiates into two layers between which is situated the line of Gennari. This is the visuo-sensory area.

The postcentral and temporal areas are differentiated for the reception of fibers of the somesthetic and acoustic pathways respectively. These represent the somestheto-sensory and auditory areas of the cortex.

In the seventh month it is possible to recognize, in the differentiation of the precentral area, an internal granular layer which becomes merged with the adjoining layer and disappears. The two inner layers become more or less

fused and in them develop certain cells of an unusually large size which are the *giant pyramidal cells of Betz*. The axones of these cells forming the pyramidal tract pass into the internal capsule, through the basis of the cerebral peduncle, and thus to the pons, medulla and spinal cord. The region represented by these axones is the precentral or motor area of the cortex. Some descending axones develop from the cells of the calcarine area which, in all probability, come from the large solitary pyramidal cells of Meynert, and pass to the anterior colliculus.

The Myelinogenetic Fields of Flechsig. Four major projection systems develop in connection with the pallium. They are distinguished both by their histological structure and their connections. These are the *archipallial projection system* from the olfactory area, and the *neopallial system* from the visual, acoustic and somatic areas. The cortical areas of the projection fibers from the three neopallial fields occupy a lateral position in the hemisphere. The visual and acoustic fields of the cortex represent specialized groups of receptors in the retina and in the internal ear. The somatic area represents receptors scattered throughout the entire body in the muscles, joints, bone and skin. The somatic projection system is both afferent and efferent; the afferent fibers serve to convey sensory impressions from the periphery, the efferent fibers conduct the impulses necessary to volitional control.

The four primary sensory motor fields of the systems just mentioned are the first to become differentiated among the various pallial cortical areas. The time at which the fibers connected with these areas receive their myelin sheaths represents the final phase in the development of the hemispherical wall. This myelinization begins at about the time of birth and continues until the beginning of puberty and probably somewhat later. The period at which the different fiber-systems receive their myelin sheaths indicates the time at which they become functionally active. This fact makes possible a myelinization time schedule of much assistance in the identification of the functional areas of the brain, known as the *myelinogenetic fields of Flechsig*.

The myelinizing process begins first in the olfactory, second in the visual, third in the acoustic, and fourth in the somatic projection fibers. The afferent projection fibers are probably myelinated shortly before the efferent ones. Myelinization proceeds by affecting the regions adjoining the primary areas which are therefore known as the *intermediate myelinogenetic fields of Flechsig*. Descending projection fibers from areas of the frontal, temporal and occipital lobes to the pons are next to receive their myelin

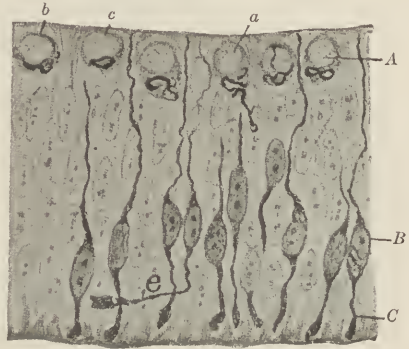


FIG. 467.—Section of the wall of the anterior cerebral cavity; embryo chick at three and one-half days of incubation. Reduced by nitrate of silver method. (Cajal.)

A, a, b, c—Nerve cells at the "apolar" stage.
B—Bipolar nerve cells. C—Cone of growth.
e—Tangential axone.

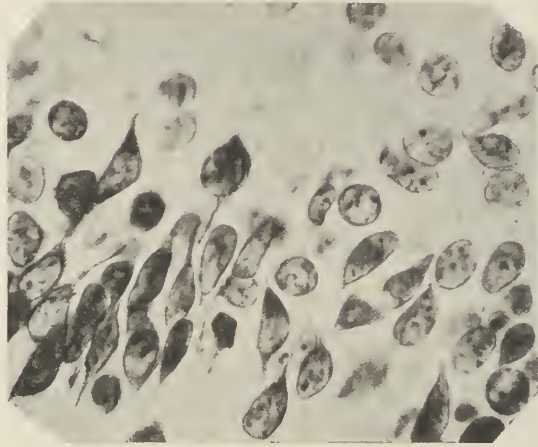


FIG. 468.—Undeveloped pyramidal cells, showing central and peripheral processes. (*His.*)

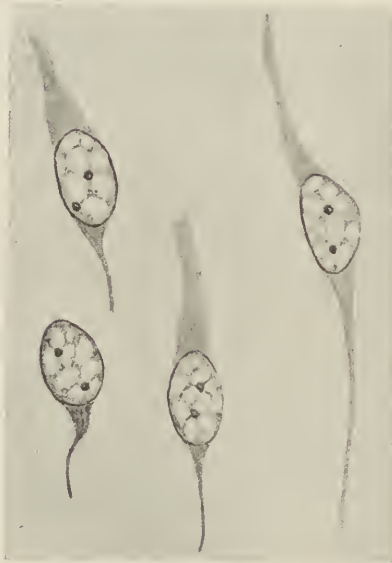


FIG. 469.—Pyramidal cells, showing central and peripheral processes, the latter above, the former below. (*His.*)

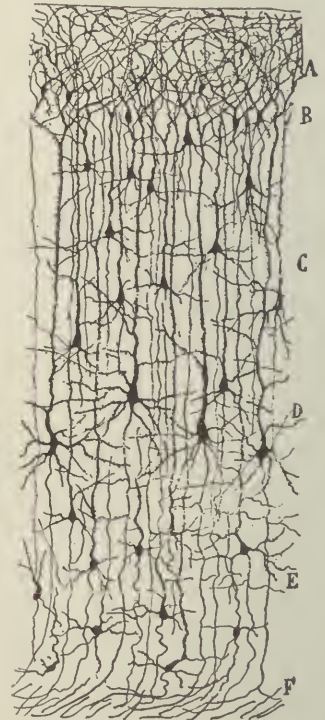


FIG. 470.—Cerebral cortex; mouse 20 days old. Golgi's method. (*Cajal.*)

A—Plexiform layer. B—Layer of small pyramidal cells. C—Layer of medium-sized pyramidal cells. D—Layer of large pyramidal cells. E—Layer of ovoid or polymorphous corpuscles. F—White substance.

sheaths. Cells whose axones form the afferent projection fibers constitute but a small portion of the endbrain. A far greater number belong to the association cells whose axones or collaterals either pass across the midline in



FIG. 471.—Diagrams of cortical areas as determined by the myelinogenetic method. (Flechsig.)

A—External surface: B—mesial surface.

The numerals indicate, in a general manner, the order of myelination. The figures show the areas into which Flechsig finds it possible to subdivide the surface according to the relative date of myelination of the fibers. It will be seen that altogether 36 areas are marked out, arranged chronologically. They form 3 main groups: a *primary*, which includes the areas numbered from 1 to 10; an *intermediate* group, from 11 to 31; and a *late or final* group, from 32 to 36. The primary areas are myelinated at or soon after birth; the intermediate do not begin to myelinate until a month after birth; and the final even later; these may not be fully myelinated eight months after birth.

the corpus callosum to the opposite hemisphere, or else extend to distant or neighboring parts of the same hemisphere. In general these association fibers acquire their myelin sheaths later than the projection systems, and their complete myelinization does not occur until late in life.

The last fibers to receive their myelin sheaths are in connection with the terminal areas of Flechsig. These areas are poor in projection fibers, although the degree of development in these terminal regions constitutes the principal difference between the human cortex and that of the closely related anthropoid forms.

The myelinization fields of Flechsig are shown in Figure 471. It is a significant fact that the terminal areas are comparatively poorly developed both in cells and fibers. Association neurones probably follow the same order of development as the projection system. They are developed first in the primary areas. The neopallial areas last acquired seem to make provision for those performances which require the newest and most highly organized adaptations. Their feebleness of development is indicative of their recent accession in the neopallial equipment. The terminal areas of Flechsig control the complex correlations of nerve impulses which result in the higher psychic faculties. It is through these areas that the different races of men, as well as individuals, attain such differing degrees of development. Lacking the degree of constancy seen in the organization of the lower portions of the neuraxis, varying in functional capacity from race to race and from individual to individual, it is not surprising that the foundations of the higher psychic faculties do not rest upon a firmer basis. Their anatomical substratum is most prone to suffer defects as a result of disease and injury leading to abnormal conditions in the higher associative correlations carried on by these newly added parts of the brain.

CHAPTER XXXVIII

THE ENDBRAIN

CEREBRAL MEASUREMENTS AND CRANIO-CEREBRAL TOPOGRAPHY

Shape, Situation, Boundaries and Surfaces. The cerebral hemispheres are ovoid in shape, presenting a large caudal pole and a smaller cephalic pole. They occupy the supratentorial portion of the posterior fossa of the skull, the lateral expansion of the middle fossa and the entire anterior fossa. Together the hemispheres present a convexity and a base. The convexity is in contact with the vault and lateral walls of the skull, while the base rests upon the orbital plate of the frontal bone, the floor of the temporal fossæ and the tentorium cerebelli. The hemispheres are separated from each other in the sagittal plane by a dense sheet of the dura mater, the *falx cerebri*. Each hemisphere, therefore, presents a mesial surface in close contact with its respective side of the falx cerebri. Detached from its fellow, the cerebral hemisphere presents an outer convex surface, the *norma lateralis*, a mesial flat surface, the *norma medialis*, and a basal irregular surface, the *norma basalis*. The cleft which separates the two hemispheres is the *great longitudinal fissure*. This separation, however, is not complete because of the presence of a large connecting mass of interhemispherical fibers constituting the *corpus callosum*.

The boundary line between the cerebral hemispheres and the brain-stem is furnished by the *great cerebral fissure of Bichat* which has a bilateral symmetry and encircles either cerebral peduncle. This fissure is continued into the horizontal portion of the fissure of Sylvius. It is continuous dorsally with the dorsal aspect of the splenium. The surface of the hemispheres is composed of a cortex which is moulded into numerous and tortuous eminences, the convolutions or gyri, which are separated from each other by fissures or sulci of varying depth.

Dimensions and Weight of the Cerebral Hemispheres. The length of the cerebral hemisphere measured from frontal to occipital pole varies in the majority of cases from 160 mm. to 170 mm. for the male and 150 mm. to 160 mm. for the female. The greatest transverse diameter of the entire brain in both sexes is 140 mm. The greatest vertical diameter is 125 mm. In brains of dolichocephalic individuals (with long heads) the fronto-occipital diameter is naturally longer than the transverse. When, however, the transverse diameter is subequal or nearly equal to the occipito-frontal diameter the condition determines the brachycephalic brain. In the brachycephalic brain there is a tendency for the longitudinal gyri to be intercepted by transverse fissures, thereby increasing the surface and hence the extent of the cortex of the brain as a whole.

The Extent of the Cerebral Cortex. Attempts to estimate the relative proportion of the gray matter in the different convolutions of the cerebrum to the degree of intelligence of the individual have been attended with little success. One investigator, Rudolph Wagner, studied the brains of four individuals, one a noted mathematician, Professor Gauss, aged seventy-eight years, another clinical teacher, Professor Fuchs, aged fifty-two years; and two individuals without special attainment. These brain surfaces were estimated by overlying the entire cortex with gold leaf. The actual difference in the cortical area of the brains examined was not so pronounced as might be expected in view of the obvious intellectual differences in the subjects studied. In fact, the general result of these observations was inconclusive concerning the relation between cortical surface and intellectual development. The following is a table quoted from Wagner's work:

COMPARATIVE MEASUREMENTS OF THE EXTENT OF SURFACE OF THE CEREBRAL CONVOLUTIONS

	Surface of each lobe separately					Free and deep surfaces of convolutions		Whole surface of cerebrum
	Frontal	Parietal	Occipital	Temporal	Central	Free surface	Deep surface including surface of insula	
Gauss.....	89,545	45,493	38,286	44,062	2,252	72,650	146,988	219,638
Fuchs.....	92,380	44,783	37,927	43,468	2,447	72,100	148,905	221,005
Woman	84,318	41,838	32,851	42,892	2,126	68,900	135,215	204,115
Workman	72,890	40,142	32,490	39,880	2,270	62,750	124,922	187,672

From these facts it will be seen that the total surface of the cortex, both exposed and sunken, averages about 200,000 sq. mm. There is about twice as much sunken cortical area as there is exposed, according to this estimate. Determinations made by subsequent observers agree with these figures in large measure. Baillarger, who dissected, unfolded and measured the whole extent of the cortex, obtained an area of 170,000 sq. mm. as a mean of the surface of the brain. Paulier, by means of Wagner's method, obtained a result similar to that of Baillarger for the entire surface. He found the sunken surface was a little more than the exposed surface and that the entire extent of the surface bears no absolute relation to the weight of the brain.

According to Danilewsky, the cortex is 33 per cent of the total weight of the brain. According to Donaldson it forms 50 per cent of the entire brain weight.

Thickness of the Cortex. The cortex varies in thickness from 1.55 mm. to 3.5 mm., the average in normal brains being 2.9 mm. If a section be taken through a gyrus, the cortex is seen to be thickest at the summit of the convolution and thinnest at its bottom bounding the sulcus. It is necessary, therefore, to take a mean between these two measurements in order to obtain the average thickness in any given locality. The cortex is somewhat thinner near the hemispherical poles. The cortex in the females is not so thick, on

the average, as that of males. The thickness of the cortex of the right hemisphere is somewhat less than that of the left, according to Donaldson.

Brain Weight. The maximum weight of the human brain in a series of 278 cases is 1,810 gm. (64 ounces); the minimum weight is about 960 gm. (34 ounces). In a series of 191 cases the maximum weight of the adult female brain was 1,585 gm. (56 ounces), and the minimum 880 gm. (31 ounces). In a large proportion of cases the weight of the male brain ranges between 46 to 53 ounces; in the female from 40 to 47 ounces. Statistics published by Peacock, Rudolph Wagner, Bischoff, Husehke, R. Boyd, Weisbach and others bear out these figures.

The mean weight of the brain in the decades between 20 and 40 years of age, according to Boyd, is 48 ounces (1,360 gm.) for the male, and 43½ ounces (1,230 gm.) for the female brain. In general the adult average male brain is heavier by 4 to 5 ounces than that of the female (about 9 per cent). The appended table gives the estimations of R. Boyd showing the mean weight of the brain in grams at different ages of the two sexes:

TABLE SHOWING MEAN WEIGHT OF BRAIN IN GRAMS AT DIFFERENT AGES

	Males	Females
Children stillborn at term.....	393	347
Children born alive at term.....	330	283
Under 3 months.....	493	451
From 3 to 6 months.....	602	560
From 6 to 12 months.....	776	727
From 1 to 2 years.....	941	843
From 2 to 4 years.....	1,095	990
From 4 to 7 years.....	1,138	1,035
From 7 to 14 years.....	1,301	1,154
From 14 to 20 years.....	1,374	1,244
From 20 to 30 years.....	1,333	1,237
From 30 to 40 years.....	1,364	1,220
From 40 to 50 years.....	1,351	1,212
From 50 to 60 years.....	1,343	1,220
From 60 to 70 years.....	1,313	1,208
From 70 to 80 years.....	1,288	1,168
Over 80 years.....	1,283	1,125

The following table compiled by Cutore gives the weight of the brain in 25 individuals from the new-born to 70 years of age, together with the length of the body, antero-posterior diameter of the brain, weight of the hypophysis, and weight of the pineal body. (See page 684.)

The weight of the brain of full-term fetuses, according to Mies, averages for males 339.25 gm.; for females 329.99 gm.

After birth the brain of the male increases more rapidly in weight than does that of the female.

The weight of the brain computed by Pfister in 156 children shows that at the end of the first year the brain is about 2½ times heavier than at birth;

WEIGHT OF BRAIN AND CORD IN 25 INDIVIDUALS AT DIFFERENT AGES

Age	Sex	Weight of body <i>grams</i>	Length of body <i>cm.</i>	Anteroposterior diameter of brain <i>cm.</i>	Transverse di- ameter of brain <i>cm.</i>	Weight of brain <i>grams</i>	Weight of hy- pophysis <i>grams</i>	Weight of pineal body <i>grams</i>
Newborn.....	Female	2,322	49.5	10.0	8.6	340	0.032	0.007
8 days.....	Female	3,030	50.0	11.5	8.8	395	0.100	0.010
1 month.....	Female	2,207	52.0	11.5	9.4	470	0.100	0.040
3 months.....	Male	3,700	63.0	13.8	11.4	762	0.110	0.035
6 months.....	Male	5,700	67.0	14.9	10.8	793	0.115	0.053
10 months.....	Female	5,972	73.0	15.0	12.0	836	0.160	0.045
13 months.....	Female	6,390	68.0	15.0	12.0	795	0.140	0.060
15 months.....	Male	6,550	73.0	17.0	12.5	872	0.170	0.025
15 months.....	Male	4,248	73.0	14.4	11.0	507	0.120	0.080
18 months.....	Female	6,200	73.5	15.8	12.5	905	0.160	0.050
20 months.....	Female	6,722	74.0	15.3	11.3	710	0.180	0.060
3 years, 3 months	Male	5,625	80.0	16.1	12.0	990	0.192	0.093
3 years, 6 months	Male	8,208	84.0	15.9	12.9	1,000	0.200	0.050
4 years.....	Female		91.0	16.5	11.8	1,075	0.190	0.070
9 years.....	Male		115.0	17.7	14.3	1,100	0.250	0.100
11 years.....	Male		120.0	17.2	13.5	1,257	0.400	0.120
13 years.....	Female		130.0	16.7	13.1	1,219	0.340	0.170
18 years.....	Male		142.0	16.7	13.2	1,200	0.310	0.125
19 years.....	Female		150.0	17.5	13.1	1,193	0.320	0.060
22 years.....	Female		165.0	18.0	13.3	1,237	0.690	0.070
23 years.....	Male		162.0	16.9	12.5	1,162	0.780	0.120
24 years.....	Male		163.0	17.9	13.6	1,300	0.440	0.220
60 years.....	Female		152.0	17.2	14.0	1,273	0.440	0.100
70 years.....	Female		147.0	16.9	13.0	1,000	0.650	0.140
70 years.....	Female		149.0	17.2	13.0	1,102	0.420	0.150

at the end of the sixth year the brain not infrequently is equal in weight to that of the adult.

Statistics collected by E. A. Spitzka, based on the brain-weight of 100 distinguished men show that the average weight of these brains was 1,469.65 gm., or fully 100 gm. above the average weight of European brains. He also showed that the senile decrease in weight is delayed about ten years in those persons who are considered distinguished.

The two hemispheres of the same brain, although hardly ever of the same weight, show no constant difference, the right half dominating about as often as the left, with an average difference of about 5 gm. according to Braune. There is no definite evidence to show that the right hemisphere is the heavier in left-handed individuals.

The Relative Weight of the Brain to the Body. This ratio is subject to great variations. In a series of 81 males the average proportion between the weight of the brain and that of the body from the second decade and later, was found to be relatively 1 to 36.5. In a series of 82 females it was 1 to 36.46.

In healthy individuals dying suddenly from acute disease or as the result of accident, the average proportion of the brain weight to that of the body is 1 to 41. According to Tiedemann, the proportionate weight of the brain to that of the body is much greater at birth than at any later period in life. In the new-born male it is about 1 to .85, and in the female 1 to 6. 5. By the tenth year this proportion has diminished to 1 to 14. At the end of the second decade the relative increase of the body is striking, the ratio of the brain to the body weight at the end of that period being about 1 to 30. After the twentieth year the average of 1 to 36.5 prevails, with some decrease in advanced life.

Relation of Stature of the Body to the Brain Weight.—According to J. Marshall, the proportion of the entire brain in ounces to each inch of stature in the male is 0.708, in the female 0.688. In the following tables compiled by Marshall from data furnished by observations of R. Boyd upon the brains of 1,150 sane persons, males 598, females 552, the average weight in ounces of the brain and its several parts is shown at different periods of life.

Brain Weight in Different Races. Estimated brain weights of different races of men have been obtained by measuring the cubic contents of the skull cavity. According to estimations by Davis, the Chinese have an average brain weight of 1,330 gm. The weight of the brain of the Sandwich Islander is 1,300 gm.; that of the brain in the Malay and American Indian is 1,265 gm., while that of the African negro averages 1,245 gm. The brain of the native Australian weighs on the average, 1,185 gm. The Hindoos also have a small brain averaging 1,190 gm. The Latin brain is somewhat less in weight than that of Teutonic and Slavonic races. This is probably due to the influence of stature on the brain.

The estimated weight of the brain of prehistoric races has also been calculated by determinations of the cranial cavity. These measurements cannot be credited with more than a fair degree of approximation to the actual conditions. The weight of a *Neanderthal* brain was about 1,000 gm., while that of the *Trinil* brain was not more than 800 gm.

Weight of the Brain Cells. The weight of all the nerve-cells in the human brain, according to Donaldson, is somewhat less than 27 grams. According to this authority the weight of the cell bodies in the cortex together with their dendrites forms only 2 per cent of the weight of the cortex, the greater portion of it being composed of axis cylinder processes and their collaterals. According to Hammarberg, a comparatively slight diminution in the development of the cortical cells is sufficient to reduce the intelligence of the individual to moderate imbecility. The total weight of these cells is relatively so small that their moderate diminution would not decrease the brain weight beyond the average degree of variation.

Cranio-Cerebral Topography. The position of the chief fissures and convolutions of the cerebral hemispheres in their relation to the surface of the head has been extensively investigated, and several systems have been employed which enable the surgeon to localize the various important areas. None of these plans is wholly correct, on account of the variability in the

TABLE SHOWING PROPORTION OF WEIGHT OF BRAIN IN OUNCES TO STATURE

MALES

Total number of cases	Ages	Stature 69 inches and upwards				Stature 68-66 inches				Stature 65 inches and under			
		Whole brain	Cerebrum	Cerebellum	Pons and me- dulla oblongata	Whole brain	Cerebrum	Cerebellum	Pons and me- dulla oblongata	Whole brain	Cerebrum	Cerebellum	Pons and me- dulla oblongata
146	20-40	49.72	43.43	5.29	1.0	47.99	41.9	5.09	1.0	46.95	41.15	4.9	0.9
337	40-70	48.15	42.1	5.09	0.96	47.08	41.01	5.1	0.97	45.74	39.88	4.96	0.9
115	70-90	46.92	41.19	4.8	0.93	46.00	40.1	4.9	1.0	44.15	38.6	4.65	0.9
598	20-90	48.40	42.34	5.09	0.97	47.13	41.08	5.06	0.99	45.61	39.84	4.87	0.9

FEMALES

Total number of cases	Ages	Stature 64 inches and upwards				Stature 63-61 inches				Stature 60 inches and under			
		Whole brain	Cerebrum	Cerebellum	Pons and me- dulla oblongata	Whole brain	Cerebrum	Cerebellum	Pons and me- dulla oblongata	Whole brain	Cerebrum	Cerebellum	Pons and me- dulla oblongata
133	20-40	44.64	39.14	4.7	0.8	42.98	37.23	4.85	0.9	42.26	36.78	4.64	0.84
299	40-70	42.67	37.21	4.63	0.83	42.75	37.29	4.56	0.9	42.49	37.08	4.54	0.87
120	70-90	41.13	35.77	4.52	0.84	39.84	34.45	4.55	0.84	39.59	34.36	4.36	0.87
552	20-90	42.76	37.32	4.62	0.82	42.37	36.84	4.64	0.89	41.53	36.17	4.5	0.86

relation of the fissures and convolutions to the skull in different individuals. The surface of the scalp is greater than the surface of the brain, so that the lines laid down do not exactly correspond to the fissures.

Several landmarks on the outer surface of the skull must first be identified in order to establish the lines necessary to cranio-cerebral localization. The most important of these landmarks are the following:

1. *The Great Longitudinal Fissure.* This fissure is indicated by a line drawn from the glabella at the root of the nose to the external occipital protuberance.

2. *The Sylvian Fissure.* This fissure is indicated by a line starting 3 cm. behind the external angular process of the orbit to a point 2 cm. below the most prominent portion of the parietal eminence. The beginning of this line corresponds to the horizontal portion of the Sylvian fissure, while the remainder, indicates the position of its lateral portion. The Sylvian point is 5 cm. behind and 1 cm. above the level of the external angular process.

This fissure begins approximately at a point 3 cm. ($1\frac{1}{4}$ inches) behind the external angular process of the frontal bone, and ends at a point 18 mm. ($\frac{3}{4}$ inch) below the parietal eminence. A straight line between these two points will represent the fissure, which is about 10 cm. (4 inches) long. The anterior 18 mm. ($\frac{3}{4}$ inch) of this line will correspond to the main portion of the fissure and the remainder to the horizontal limb. The vertical limb ascends for about 2.5 cm. (1 inch) from the lateral end of the main fissure. Around the posterior end of the horizontal limb, and approximately under the parietal eminence, lies the supramarginal convolution. It is continuous in front with the ascending parietal convolution and behind with the angular gyrus.

3. *The Tentorial Hiatus or Transverse Fissure.* This fissure, between the cerebral hemispheres and the cerebellum corresponds to a line drawn from the inion to the external auditory meatus.

4. *The Rolandic Fissure.* The position of the dorsal extremity of this fissure is found by measuring 55.6 per cent of the whole distance from the glabella to the external occipital protuberance. This point may be estimated by taking half of the distance from the glabella to the external protuberance over the top of the head, which thus determines the midpoint of the vertex. A point one-half inch behind this point indicates the dorsal extremity of the central sulcus. This measurement suffices for all practical purposes and is especially recommended because of its simplicity. From the point indicating the dorsal extremity of the central fissure, a line drawn downward 9 to 10 cm. in length, at an angle of 67 degrees with the midline, indicates the course and position of the central fissure. This angle may be somewhat larger, even as great as 71.5 degrees. An instrument known as the *cyrtometer* provides a scale of measurements for localizing the central fissure. Still another method of localizing this fissure is that of Reid, according to which the great longitudinal fissure is indicated on the surface as well as the Sylvian fissure.

Many methods have been devised for the purpose of establishing the line of this fissure on the scalp.

Chiene's method consists of folding an ordinary square sheet of paper diagonally, thus dividing an angle of 90 degrees in half to make two of 45 degrees. One of these angles of 45 degrees is again halved in a similar manner, making two new angles of $22\frac{1}{2}$ degrees each. The paper is then so unfolded that one of the new angles of $22\frac{1}{2}$ degrees is added to one of 45, making a new angle of $67\frac{1}{2}$ degrees. This will indicate with sufficient accuracy the angle of the fissure of Rolando with the midsagittal line.

Horsley's crytometer consists of two strips either of parchment paper or of thin, flexible metal, each graduated in inches. The lateral arm is placed at an angle of 67 degrees with the long arm, the apex of the angle being at a point 12 mm. or one-half inch behind the mid-point of the long arm.

Anderson and Mackins have suggested: (1) A median sagittal line from the glabella to the inion; (2) a frontal line from the midsagittal point to the depression just in front of the ear at the level of the upper border of the meatus; (3) a squamosal line from the border of the orbit to the junction of the middle and lower thirds of the frontal line, and prolonged for about 3.7 cm. ($1\frac{1}{2}$ inches) behind the frontal line. The upper extremity of the central fissure is situated between the midsagittal point and a point 18 mm. ($\frac{3}{4}$ inch) behind it, and the lower extremity of this fissure they located near the squamosal line about 18 mm. ($\frac{3}{4}$ inch) in front of its junction with the frontal line. The beginning of the lateral portion of the Sylvian fissure is not a definite point, but will usually be encountered at a point from 3.5 to 5 cm. ($1\frac{1}{2}$ to 2 inches) behind the angular process, the course of the horizontal portion of this fissure corresponding closely to the squamosal line (Mills).

5. *The Occipital Fissure.* This fissure runs across the dorsal surface of the cerebrum at right angles to the great longitudinal fissure about 2 to 3 cm. from a point .5 cm. in front of the *lambda* (posterior fontanel). According to Reid, if the Sylvian fissure be projected to the sagittal suture, the last 2 or 3 cm. of this line will indicate the position of the occipital fissure.

6. *The Precentral Sulcus.* This fissure begins 2 cm. in front of the middle of the central fissure and extends almost but not quite to the Sylvian fissure.

7. *The Superior Frontal Fissure.* This sulcus runs backward from the supra-orbital notch parallel with the line of the superior longitudinal fissure to a point 1 cm. in front of the line which indicates the position of the central fissure.

8. *The Inferior Frontal Fissure.* This sulcus follows a course coincident with the temporal ridge of the frontal bone.

9. *The Intraparietal Fissure.* This fissure, consisting of the post-central, intraparietal and postparietal fissures, begins on a level with the junction of the middle and lower thirds of the central fissure, and follows a line carried across the head from the root of one auricle to that of the other auricle for about 3 cm. It first passes upward and then curves backward to lie

parallel with the longitudinal fissure midway between it and the parietal eminence. It then curves downward to end between the posterior fontanel and the parietal eminence.

The *medulla oblongata* occupies a position 5 cm. mesial to the lateral surface of the mastoid portion of the temporal bone. It is situated caudal to a plane passed through the two external meati.

The *pons Varolii* extends for 2.5 cm. above the level of the external auditory meatus and protrudes forward in such a way that it reaches a plane marked by the anterior wall of the meatus. Between the wall of the skull and the upper three-quarters of the pons, the temporal lobes are interposed.

The Cerebral Hemispheres. The dorso-mesial border of the hemisphere extends from the fronto-nasal suture caudal to a point corresponding to the external occipital protuberance. Neither hemisphere quite reaches the midline, and each is separated from its fellow by the interval which corresponds to the superior longitudinal sinus. This interval is the greatest in relation with the occipital lobes, where it measures 1 cm. in width. Ventral to the longitudinal sinus the mesial surfaces of the hemisphere are more nearly in contact and are separated only by the falx cerebri. The most cephalic extent of each hemisphere at the frontal pole is a line indicated by the eyebrow. Laterally, its ventral boundary is the zygoma; and caudally, the superior curved line of the occipital bone. The orbital border of the hemisphere commences mesially near the nasion at a point 1 cm. from the midline. From this point it ascends in an arch, and passing laterally follows a line about 8 mm. above the center of the supra-orbital ridge of the frontal bone. Laterally it descends again, crosses the temporal line immediately below the most depressed portion of the fossa in the frontal bone, above the external angular process. The orbital margin then passes caudally and slightly ventrally through the cephalic portion of the temporal fossa to a point 25 or 30 mm. behind the external angular process. The orbital margin is first separated from the lateral margin of the temporal lobe by a broad groove which gradually becomes reduced in size as the two margins approach each other. The occipito-temporal margin of the hemisphere begins caudally, in relation with the occipital pole at a point 5 to 15 mm. dorsal and lateral to the external occipital protuberance. The line which marks it passes in a horizontal direction forward with a slight convexity upward. It reaches the ear, crosses the supramastoid ridge, and then is continued for 6 mm. above the external auditory meatus. Its further prolongation is on a level with the upper border of the zygomatic arch in the caudal half of its length. The line indicating the occipito-temporal margin then curves upward and reaches its cephalic extremity at the temporal pole of the hemisphere above the zygoma, and 15 mm. behind the external angular process. From this position it turns forward and upward to meet the caudal extremity of the frontal margin.

The Relations of the Convolution to the Skull. The superior and middle frontal convolutions are in relation with the frontal region of the frontal

bone, the superior frontal convolution occupying the inner half and the middle convolution the outer half. The frontal eminence is usually situated over the middle frontal convolution.

The pars triangularis of the inferior frontal convolution corresponds to the antero-inferior angle of the parietal bone.

The pars orbitalis is covered by the temporal portion of the frontal bone and the upper end of the greater wing of the sphenoid. The parietal lobe is in relation with the parietal bone and the parietal eminence corresponds to the supramarginal convolution.

The occipital lobe is in relation with the portion of the occipital bone above the groove for the lateral sinus.

The temporal lobe occupies a position for the most part beneath the squamous portion of the temporal bone and the postero-inferior quarter of the parietal bone. The anterior extremity of the temporal lobe projects under the lesser wing of the sphenoid and rests upon the greater wing.

The pole or angle of the insula is situated 15 mm. mesial to the Sylvian point. The island of Reil extends forward about 10 to 15 mm. in front of this point and backward about 35 mm., where it follows the line of the horizontal branch of the Sylvian fissure. The surface of the insula recedes from the surface of the skull in passing from its pole to its posterior angle, which lies at a depth of 25 mm. from the outer surface of the skull. The vertical extent of the island of Reil in the region of its pole is 25 mm.; caudally it gradually diminishes.

The Projection of the Lateral Ventricle on the Surface of the Skull.

When projected upon the surface of the skull the entire extent of the cavity of the lateral ventricle with the exception of the occipital horn is in relation with the temporal fossa. The foramen of Monro is situated 4 to 5 mm. above the horizontal branch of the Sylvian fissure. The frontal horn reaches forward beyond this opening to a point slightly beyond the coronal suture, while the body extends backward to the temporal ridge in front of which it turns downward to terminate in the temporal and occipital horns. The temporal horn follows the direction of the middle temporal convolution and ends about 30 mm. behind the temporal pole. The general cavity of the lateral ventricle, with the exception of the temporal horn, is relatively small. The temporal horn is a relatively large cavity. It is situated mesial to the dorsal part of the middle temporal convolution and is about 35 mm. from the surface. It may be punctured at a point 40 mm. above and 25 mm. behind the external auditory meatus.

Cranial Points. Certain points on the surface of the skull frequently serve to facilitate description and localization. A number of these points often appear in the literature, especially in anthropometric discussions. They may therefore be of service to the student.

Bregma: The point at which the sagittal and coronal sutures meet.

Obelion: A point in the sagittal suture midway between the parietal foramina.

Lambda: The point at which the sagittal and lambdoid sutures meet.

Inion: The most prominent point on the external occipital protuberance.

Opisthion: The mid-point on the posterior margin of the foramen magnum.

Basion: The mid-point on the anterior margin of the foramen magnum.

Prosthion: The most prominent point on the alveolar margin between the two upper median incisor teeth.

Akanthion: The most prominent point on the nasal spine.

Rhinion: The most prominent point at which the nasal bones touch each other.

Nasion: The point at which the internasal suture meets the nasofrontal suture.

Glabella: The most projecting point of the frontal bone, at the level of the supra-orbital ridges.

Pterion: A point at the posterior end of the parieto-sphenoid suture

Stephanion: The point of intersection of the coronal suture and the temporal ridge. Where an epipteric bone is present the exact situation of this point is indeterminate.

Asterion: The point of confluence of the lambdoid, squamo-parietal and squamo-occipital sutures.

Pogonion: The most prominent point of the chin.

Dacryon: The point of confluence of the fronto-lachrymal, fronto-maxillary and lachrymo-maxillary sutures on the inner orbital wall.

Cranial Indices. Certain indices may be obtained for expressing the degree of development of the cranium and thus indirectly shedding light upon the development of the brain. The indices most commonly employed as follows:

1. The *cephalic* or *breadth index*, by which cranial breadth and length are compared.

2. The *altitudinal* or *height index*, by which cranial height and length are compared.

3. The *alveolar index*, by which the lines from basion to nasion, and to prosthion respectively are compared.

4. The *nasal index*, whereby the width and height of the nose (the nasal aperture of the cranium) are expressed.

5. The *facial index*, by which the height and breadth of the facial part of the skull are compared.

6. The *stephano-zygomatic index*, by which the interstephanic and bi-zygomatic diameters are compared.

TABLE SHOWING CRANIAL INDICES.

METHOD OF OBTAINING INDICES	CLASSIFICATION OF INDICES	NOMENCLATURE	GENERAL INDICATION
1. BREADTH:			
Maximum breadth $\times 100$	Below 75	Dolichocephalic (Long headed)	Variable, and dependent on age, sex, race.
Maximum length	Between 75 and 80 Above 80	Mesaticephalic Brachycephalic (Broad headed)	
2. HEIGHT:			
Basal height $\times 100$	Below 72	Tapeinocephalic	In general, the lower the index, the lower the cranial form.
Maximum length	Between 72 and 77 Above 77	Metriocephalic Akrocephalic	
3. ALVEOLAR:			
Basion to Prosthion $\times 100$	Below 98	Orthognathous	The greater the index, the greater is the projection of the jaw, and consequently the more ape-like is the countenance.
Basion to nasion	Between 98 and 103 Above 103	Mesognathous Prognathous	
4. NASAL:			
Nasal width $\times 100$	Below 48	Leptorrhine	Lower forms of crania have the greater indices.
Nasal height	Between 48 and 53 Above 53	Mesorrhine Platyrrhine	
5. FACIAL:			
Nasion to prosthion $\times 100$	Below 50	Chameprosope	Generally the lower forms have the lower indices.
Bizygomatic breadth	Above 50	Leptoprosope	
6. STEPHANO-ZYGOMATIC:			
Inter-stephanic breadth $\times 100$	Below 100	Phenozygous	In the lower cranial forms the index is below 100.
Bizygomatic breadth	Above 100	Cryptozygous	
7. ORBITAL:			
Orbital height $\times 100$	Below 84	Microsemic	Indication variable: generally speaking, lower human forms have lower indices.
Orbital width	Between 84 and 89 Above 89	Mesosemic Megasemic	

CHAPTER XXXIX

THE ENDBRAIN

THE COVERINGS OF THE BRAIN

The Significance of the Coverings of the Brain. The head, developing as it does, in response to the demands of the organism for a structure adequate to perform its varied functions, has acquired a series of concentric tissue layers of varying kinds which amply provide for its solidity and the protection of the most highly developed and specialized region of the central nervous system enclosed within it. As may be readily grasped from the description of the development of the head under the discussion of the medulla oblongata, the forward end of the organism early became the means by which the body learned of the existence and brought about the procurement and ingestion of its food. It also, by means of the mouth and the organs of special sense, became the forward moving end of the organism, thus determining the polarity of the body, and finally by the development of heavy jaws and formidable teeth became the main organ of offense and defense possessed by the body. These duties and functions have laid upon the head end of the organism the responsibility of meeting and bearing the brunt of many factors inimical to the existence of the individual. Evolution has met these extra hazards by the development about the delicate organs of special sense and the vital portions of the central nervous system of a series of envelopes or coverings which vary in their structure and supply different forms of protection to the enclosed parts. The main feature of the protective envelopes is their highly resistant character. The protective envelopes consist of the *skull*, the *dura mater* and the *cerebrospinal fluid*. The skull, consisting of two layers of hard, dense bone connected by a layer of spongy cancellous tissue, is admirably constructed as a stress- and strain-bearing structure. The dura, consisting almost entirely of dense white connective tissue, is likewise a strong and resistant tissue. The cerebrospinal fluid, partaking of the common characteristics of all fluids, being noncompressible and liquid, is admirably suited to take up and equalize in all directions all factors bringing pressure to bear upon the central nervous system.

These characteristics are, however, a potent source of danger to the delicate structures contained within the coverings of the brain on account of both extrinsic and intrinsic harmful influences. In the case of trauma by extrinsic factors, if the stress be too great for the envelope to sustain, the bony tissue splinters with the formation of fractures, fissured, com-

minuted or depressed, which not only may result in injury to the underlying nervous tissue, but also may cause damage at points relatively far distant from the point of impact. The cerebrospinal fluid, by its unyielding equalization of pressure, may serve to transmit directly to the nervous system forces which may bring about the destruction of the delicate nerve cell. In the case of intrinsic disturbances, the firm unyielding character of the dura and cranium produces a rigid limitation of the intracranial contents. With the development of expanding neoplasms within the skull, the limitations to growth brought about by the dura and skull cause the most extreme disturbances to be visited upon the softer, more yielding and vulnerable nervous tissues. The rôle of the cerebrospinal fluid as a source of danger to the central nervous system exists in the wide open pathways which lie before an infection entering the subarachnoid space, whence it may rapidly and widely disseminate over the entire length and breadth of the brain and spinal cord. Under certain conditions, therefore, the very advantages of these coverings of the brain are their disadvantages; but under normal circumstances they are admirably fitted to play their parts in the protection of the central nervous system.

The Embryological Development of the Coverings. The embryological development of the spinal and cerebral divisions of the same membrane is similar. They develop by a series of concentric splittings of the mesoderm surrounding the central nervous system, a series of delaminations resulting in the thin membranous layers surrounding the cerebrospinal axis. The embryological differentiation between the two systems must always be remembered, the axis being ectodermal and the coverings mesodermal in derivation. The origin of the cerebrospinal fluid is probably due to the liquefaction of certain mesodermal cells and the seepage through the embryonic membranes of tissue fluids; for evidence of the presence of some sort of liquid can be substantiated long before the chorioidal glands have attained anything approximating a functional status. The tissues composing the bony covering arise both from membrane and from cartilage, and they also are strictly mesodermal in origin.

Location of the Coverings. The coverings of the brain are morphologically the same as the coverings of the spinal cord. The most external is the covering composed of the bones which form the skull, exclusive of the bones of the face. The next internal is the dura mater, the outer layer of which forms the internal periosteum of the bones of the skull and is continuous at the foramina and in early life through the suture lines with the external periosteum of the cranial bones. Within the dura and separated from it by a potential space is the arachnoid. The pia mater is the most internal of the coverings and lies in intimate relationship with the cerebrospinal axis. At certain points, the pia actually extends into the cavity of the axis and is surrounded on all sides by the central nervous tissue. Between the pia mater and the arachnoid lies the subarachnoid space, reduced to a mere slit in some regions, expanded into capacious spaces in others, and containing the fluid covering of the nervous system, the cerebrospinal fluid.

THE OSSEOUS COVERING

The first covering of the central nervous system is the bony framework of the skull, and this can be divided into that portion which forms the base of the skull and that which forms the cranial vault or the calvarium. The structure of the base of the skull has been described in detail in Chapter XIII, and that portion of the bony covering of the central nervous system which constitutes the vault of the skull may now be examined.

The vault of the skull separated from the base is an oval, broader and deeper behind than in front. It consists of four bones, the *frontal bone*, forming the upper and anterior limit, the *occipital bone*, its posterior and lower limit, and its lateral walls formed by the *two parietal bones*, the uppermost tip of the *greater wing of the sphenoid*, and a crescentic portion of the *squamous portion of the temporal bone* which lies above the plane of section. Viewed from within it presents a deep concavity, greatest in depth and width at about the junction of the cephalic three-fifths with the caudal two-fifths. It is crossed by a number of *sutures*, the *fronto-parietal* and the *fronto-sphenoidal* cephalically, the *parieto-sphenoidal*, the *interparietal* and the *parieto-squamosal* in the middle portion, and the *parieto-occipital* caudally.

In young subjects, the remains of the metopic or interfrontal suture may be found in the middle part of the frontal bone.

Along the course of the lambdoid or parieto-occipital suture, there will occasionally be found small separate bones, called *Wormian bones*. These are rarely found along the course of the interparietal suture and more rarely still along some of the other sutures.

Interior Markings of the Skull. The vault of the skull presents a number of grooves and impressions. The grooves for the branches of the *middle meningeal arteries* appear on the squamosal surface and radiate from that point forward, backward and upward, diminishing in depth as they approach the midline. At some points, these grooves are bridged over and the meningeal artery then lies within a canal in the bone. These grooves are particularly numerous in the parietal region of the vault. Cephalically in the midline is the frontal crest, which diminishes as it is followed upward and backward. This crest begins at the base of the crista galli and affords attachment to the falx cerebri. In some instances the ridge is double, presenting thus a groove between the two ridges in which is lodged the beginning of the superior longitudinal sinus. On either side of the interparietal suture may be seen depressions in the bone which indicate the location of the *Pacchionian bodies*. When viewed by transmitted light, these areas are much thinner than the surrounding bony tissue, and in extreme cases the bone may be completely eroded by these bodies. The inner surface of the vault of the skull, particularly in the frontal region, may be marked by ridges and depressions corresponding to the gyri and sulci of the underlying cerebral tissue. A short distance caudad to the deepest portion of the vault, on each side of the interparietal suture, is the *parietal foramen* which affords a communication between the superior longitudinal sinus

and the epicranial plexus of veins. The occipital bone closes in the vault caudally and presents a crest beginning cephalically and becoming more and more prominent until it ends in the internal occipital protuberance. This is the *internal occipital crest* which affords attachment to the caudal termination of the falx cerebri. Usually on the right side of this crest there is a relatively deep groove which lodges the superior longitudinal sinus just before it reaches the *torcular Herophili*. On either side of the internal occipital crest is the *superior occipital fossa* which receives the *occipital pole* of the cerebrum.

The Structure of the Osseous Covering. In structure, the vault consists of two compact layers of bone, called the *outer* and *inner tables*. These layers are formed of dense compact osseous tissue. Between these two tables, is situated a layer of cancellous bone, the *diploë*, within which run the thin walled venous channels called the *diploic veins*.

The Blood Supply of the Osseous Covering. The vault is supplied with blood by means of vessels which enter the bony tissue from both the outside or epicranial surface and the inside or dural surface. These vessels are very numerous, as may readily be seen when the dura is stripped from a fresh calvarium.

The Periosteum. The bones of the vault are covered with periosteum both internally and externally. The internal periosteum is supplied by the outer layer of the dura and is continuous with the external periosteum at the foramina and at the suture lines.

The Continuity of the Coverings of the Central Nervous System. The various protective and nutritive coverings of the central nervous system are continuous envelopes. The osseous covering consists of the vertebræ and the cranium. The dura mater is divided for the convenience of description into two portions, the spinal and the cranial, which are continuous at the foramen magnum. The fluid envelope is, of course, in direct continuity within the cavity of the vertebral canal and the cranium, a constant flow taking place from one to the other, according to the general plan of the circulation of the spinal fluid. The arachnoid and the pia mater likewise extend uninterruptedly about the entire central nervous system, the cranial arachnoid and pia mater becoming the spinal arachnoid and pia mater at the foramen magnum. Although the distinction between the cranial and spinal membranes is conventional, and mainly for the sake of descriptive purposes, nevertheless the cranial and spinal membranes differ in certain particulars.

THE CRANIAL DURA MATER

The dura mater is the most external of the membranous envelopes surrounding the brain and lies in intimate contact with the inner table of the skull. It is separated from the bones of the skull by a cleft called the *epidural space* which is traversed by prolongations of the dura. This cleft is a potential line of cleavage and may be converted into a real space by

hemorrhage between the skull and the dura. The inner surface of the dura is in contact with the arachnoid, and the two surfaces are kept in apposition not only by the pressure within the arachnoid, but also by delicate tissue bridges which cross from the dura to the arachnoid. Between the two membranes is the *subdural* or the *supra-arachnoid space*, which is filled by a very small quantity of lymphatic fluid. From the subdural *space* the lymph is probably carried off by absorption into the capillaries running in the inner layer of the dura mater.

The cranial dura differs from the spinal dura in that it consists of two layers, an outer, which forms the internal periosteum of the cranial bones, and an inner, which is the true dura. At the foramen magnum these two layers separate, the outer being continued as the periosteum of the lining of the

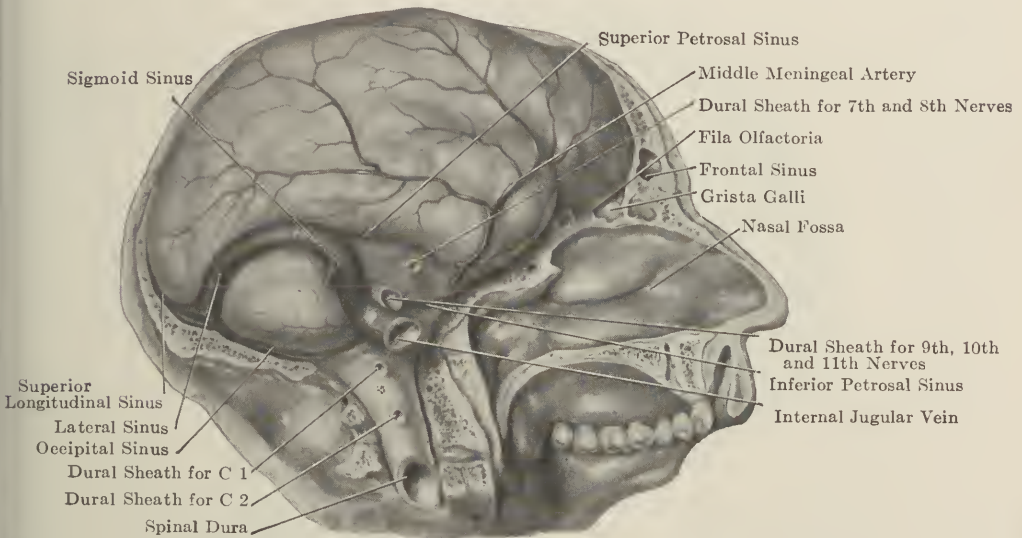


FIG. 472.—The dura mater, middle meningeal artery and lateral sinus.

foramen magnum, and the inner as the true spinal dura mater. The outer layer of the dura mater is in contact throughout with the inner table of the skull, being intimately adherent to the bone at the suture lines, the foramina both of the vault and base, and over the osseous inequalities which especially feature the base. This adherence between bone and dura varies with the individual and becomes progressively more intimate with increasing years. It is scarcely demonstrable in fetal life and early infancy. The points of bony irregularity, where the dura is particularly adherent, are the crista galli, the free borders of the lesser wings of the sphenoid, the circumference of the sella turcica and the dorsum sellæ, the ridges which mark the inner surface of the frontal and occipital bones and the superior border of the petrosa.

The outer layer of the dura also serves to carry the meningeal arteries and veins. These vessels enter the skull at a number of points, pass to the

dura, within which they ramify, and eventually terminate by supplying the bones of the skull and the dura mater.

The inner layer of the dura mater is much more delicate in structure than the heavy outer layer. It is richly vascular, the vessels in the main being small. The two layers are fused into one by the passage between them of many strands of fibrous tissue which interlace in all directions. The existence of the two layers as separate structures can readily be demonstrated, for with a little care an instrument such as a grooved director may be introduced between the two layers and their connection one with the other divided, thus forming two distinct layers. The inner layer is prolonged into the cavity of the cranium in the form of a number of partitions which serve to divide the cranium incompletely into a number of com-

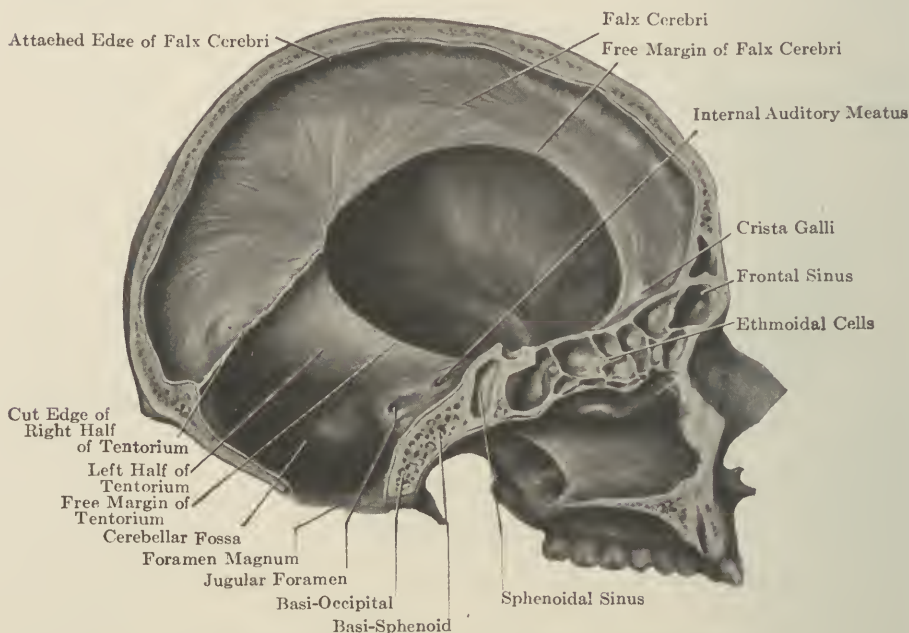


FIG. 473.—Lateral view of the interior of the skull.

partments. These prolongations are for the purpose of confining and supporting the various parts of the brain, so that the soft nervous tissue will not be seriously affected by changes in the position of the head.

At some points the two layers of the dura separate to enclose certain structures, which are the dural sinuses and the parasinoidal lacunæ, the Gasserian ganglion and the hypophysis.

The Dural Reduplications. The reduplications of the inner layer of the dura mater are four in number, the *tentorium*, the *falx cerebri*, the *falx cerebelli*, and the *diaphragma sellæ*.

THE TENTORIUM. The *tentorium* is arranged in a more or less transverse plane and serves to separate the posterior cranial fossa from the remainder of the cranial cavity. It is tilted somewhat from above down-

ward, outward and backward, and is pierced at the middle of its cephalic border by the *incisura tentorii* which serves for the passage of the brain-stem and other structures. It presents an upper and a lower surface, a free and an attached border and the terminations of the two borders. Within the substance of the tentorium, in the midline and passing directly backward and downward, is the *straight sinus* which is formed by the confluence of the *great vein of Galen* with the termination of the *inferior longitudinal sinus*. The upper surface supports the tentorial surfaces of the occipital lobes of the cerebrum. The lower surface is a shallow vault and lies in contact with the tentorial surface of the *superior vermis* and the *hemispheres* of the *cerebellum*. The dorsal surface receives the termination of the *falx cerebri* and the ventral surface the termination of the *falx cerebelli*.

The attached border of the tentorium begins caudally on each side at the internal occipital protuberance. It is split into two layers, an upper and a lower, which are attached respectively to the upper and lower lips of the horizontal arms of the *cruciform sulcus* on the internal surface of the occipital bones, thus including between them the beginning of the *right* and *left lateral sinuses*. This attachment continues along the junction between the vault and base of the cranium until the posterior inferior angle of the parietal bone is reached, at which point the lateral sinus leaves the tentorium and swings downward and inward to continue its course toward the jugular foramen. The attached border of the tentorium from this point passes inward and forward and gains the *superior border* of the *petrosa* which it follows, enclosing between its edges the *superior petrosal sinus*. Just before it reaches the tip of the petrosa, it divides into two layers to form the *cavum Meckeli* which lodges the Gasserian ganglion. It then swings inward and becomes attached to the tips of the *posterior clinoid processes*, crossing below the prolongation of the free border, which is continued forward to be attached to the *anterior clinoid processes*.

The free border of the tentorium encloses the *incisura tentorii* and is much less extensive than the attached border. It forms an irregular ellipse, broader caudally and flattened cephalically, where it is completed by the upper border of the *dorsum sellæ*. The terminations of the free border of the tentorium are carried forward above the terminations of the attached border to become adherent to the anterior clinoid processes. As they pass above the terminations of the attached border a curved reduplication passes off laterally and downward to join the attached border, thus closing in the space between the extremities of the free and attached borders. Through this triangular space so formed pass the three oculomotor nerves, the third cranial nerve superiorly, the fourth cranial nerve laterally and the sixth cranial nerve inferiorly.

THE FALX. The *falx*, so-called because of its sickle-shaped contour, is disposed in the midsagittal plane of the skull and serves to divide incompletely the cavity of the skull into two lateral halves. It is subdivided by the tentorium into two portions, the *falx cerebri* and the *falx cerebelli*. The former, of much greater extent than the latter, lying above the tentorium,

separates the cerebral hemispheres; whereas the falx cerebelli is of only slight extent and lying below the tentorium serves incompletely to separate the two lateral hemispheres of the cerebellum. The falx cerebri begins cephalically at the crista galli as a narrow band presenting two lateral surfaces and a free and an attached border. The attached border is adherent to the inner table of the frontal bone and soon splits into two limbs which enclose the beginning of the *superior longitudinal sinus*. Proceeding upward and backward the attached border passes successively over the frontal bone, along the interparietal suture to the *lambda*, and ends at the internal occipital protuberance. The free border begins cephalically at the crista galli, and passing at first upward and backward, then backward and downward, presents a flat arch ending on the upper surface of the tentorium. The

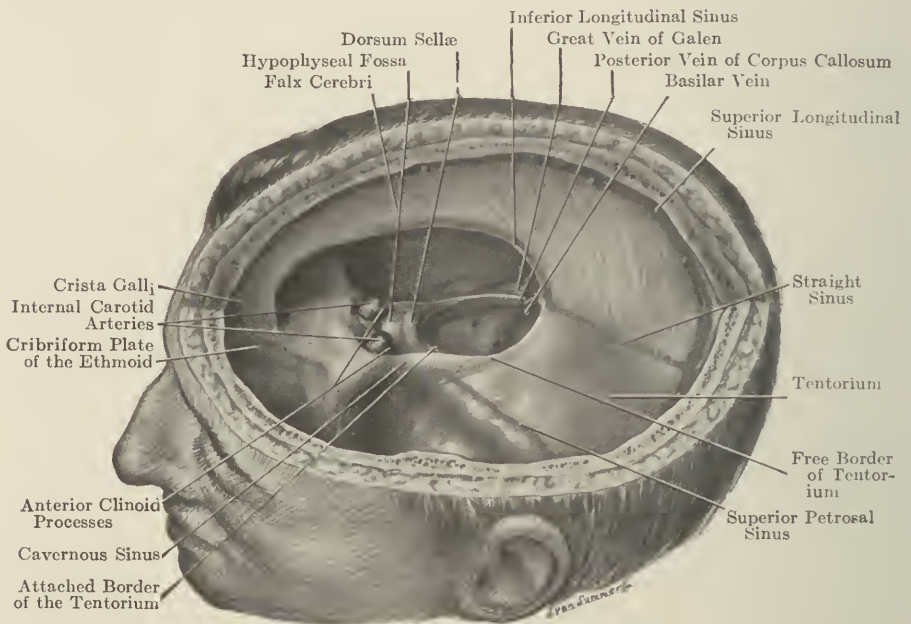


FIG. 474.—The falx cerebri and tentorium.

extent of the attached border is much greater than that of the free border which contains within it the *inferior longitudinal sinus*.

At numerous points along the course of the superior longitudinal sinus, veins pass from the pia across the subarachnoid space through the arachnoid and reach the sinus, into which they pour their contents. The free border of the falx lies above the corpus callosum and is separated from that structure by a vertical distance which gradually decreases as the tentorium is approached; but the inferior border of the falx never actually comes into contact with the corpus callosum.

The lateral surfaces of the falx cerebri increase in vertical height from before backward to a point corresponding to the greatest height of the cranial vault, and then decrease to a slight extent as the tentorium is

approached. In many instances the falx is fenestrated, and these openings may be so extensive as to reduce the falx to a lacework. Occasionally, irregular plates of bone are formed within its substance, which is reminiscent of some of the lower forms in which all of the dural reduplications are bony formations. Posteriorly the falx presents a tentorial border at the point where the membrane meets the tentorium as that membrane passes transversely across the cavity of the skull. At the point of junction between the falx cerebri, tentorium and falx cerebelli is located the straight sinus.

THE FALX CEREBELLI. The *falx cerebelli* is much less in extent than the falx cerebri and is attached to the under surface of the tentorium. It thus presents three borders and two lateral surfaces. The tentorial border corresponds in depth to the extent of the tentorium to which it is attached. The attached border is adherent to the two lips of the inferior limb of the cruciform ridge of the occipital bone and encloses the occipital sinus. The free border is sickle-shaped and begins at the cephalic edge of the tentorium. Passing at first backward and downward and then downward and forward, it splits into two prolongations which pass forward and fuse with the dura along the foramen magnum. The free border at its origin lies in contact with the superior vermis, but recedes from that structure as the falx shortens in its antero-posterior diameter. The two lateral surfaces serve to separate incompletely the two hemispheres of the cerebellum. The falx cerebri and falx cerebelli are really separate portions of an originally undivided median septum, beginning at the crista galli cephalically and ending at the foramen magnum caudally. The subdivision into cerebral and cerebellar portions is apparently a secondary development in the interest of adding stability to the falx and of confining the cerebrum and the cerebellum to their appropriate parts of the cranial cavity.

THE TENTORIUM OF THE HYPOPHYSIS CEREBRI. The *hypophysis cerebri* is situated within a fibro-osseous quadrilateral space. This *pituitary fossa* is limited caudally by the dorsum sellæ. As the dura mater passes forward from the summit of the dorsum sellæ, it separates into its two layers. The outer layer descends and forms the covering of the bone, while the inner layer forms the roof of the fossa. Laterally the space between the anterior, middle and posterior clinoid processes is enclosed by a heavy fold of dura, within which is situated the *cavernous sinus*. The outer layer of the dura mater forming the floor and the inner layer forming the roof, meet and fuse at the caudal edge of the *optic groove*. The roof of this fossa is called the *diaphragma sellæ* and is pierced by the *infundibular stalk* descending from the floor of the third ventricle to the hypophysis. The superior surface of the diaphragm is in relation with the inferior olfactory convolutions, the optic chiasm, and the tuber cinereum. The inferior surface is in relation with the upper surface of the hypophysis.

One further reduplication of the dura has been described in the form of a shallow pocket in the dura on the floor of the anterior cranial fossa, which serves to receive the tip of the olfactory bulb.

The Minute Structure of the Dura Mater. The outer layer of the dura mater is a heavy whitish-yellow membrane and serves to conduct the larger

vessels of the meningeal system. It consists of bands of dense white fibrous tissue which run in all directions, interlacing one with the other. Interspersed within the strands of white fibrous tissue are smaller and less conspicuous bundles of yellow elastic tissue. Within the spaces between the bands of white fibrous and yellow elastic tissue lie a number of connective tissue cells. There are also a number of larger cells which seem to be plasma cells. Medullated nerve fibers and a moderately rich vascular network are contained within the dural membrane. The nerves end in a fine diffuse network of non-medullated fibers. The inner layer of the dura is much less dense than the outer layer, to which it is connected by many fine bands of connective tissue. It consists of less white fibrous tissue and more yellow elastic tissue than is present in the outer layer. The inner layer is also more cellular. The bands of fibers in the reduplication of the dura forming the falx cerebri, falx cerebelli and tentorium tend to follow certain definite lines. In the falx they radiate toward the convex border; cephalically, at the origin of the falx arising from the crista galli, there are a large number of irregularly interlacing bands of fibrous tissue which pass upward and backward. In the tentorium the fibers pass out from the base of the falx cerebri into the tentorium and radiate outward toward its circumference. The internal surface of the inner layer of the dura, which comes into contact with the outer surface of the arachnoid, presents a layer of flat endothelial cells moistened by the lymph which is present in the subdural space.

In many specimens of dura mater there may be found small gritty bodies called brain sand or *acervulus*. These consist of deposits of calcium carbonate and calcium phosphate within a fibrous tissue capsule. They are most numerous in individuals of advanced years and may be present in such large numbers as to produce a distinct gritty resistance to the knife.

THE ARACHNOID

The *arachnoid*, so-called because of its resemblance to a spider web, is the intermediate covering between the dura and the pia mater. It is connected with both of these membranes by fine strands of tissue which traverse the subdural and the subarachnoid spaces. This relationship and union is much more intimate with the pia than with the dura; in fact so closely associated are the pia mater and the arachnoid at some points, that they fuse and form one membrane, the *pia-arachnoid*. At other points the arachnoid is widely separated from the pia and forms certain fluid-filled spaces which are called the *cisterns*.

The arachnoid may be viewed as a serous membrane consisting of two layers, an outer or parietal layer in contact with the dura mater and an inner or visceral layer in contact with the pia mater, and containing within these two layers the arachnoidal cavity. This cavity may be the site of extravasation from vessels crossing through the arachnoid to the pia mater.

The arachnoid appears as a sack enclosing the entire brain and spinal cord, which is complete and at no point allows communication between the

subarachnoid and the subdural spaces. It lies in contact with the pia mater over the summits of the various irregularities of the brain mass. It does not follow the surface contour of the brain, but bridges across from one irregularity to the other by the shortest course, thus creating spaces between the arachnoid and the pia mater called the *subarachnoid spaces*. For the sake of descriptive purposes, the arachnoid may be divided into two general divisions, the *arachnoid of the base*, and the *arachnoid of the convexity*.

The Basilar Arachnoid. The arachnoid of the base may be conveniently studied by examining its behavior in the various regions of the brain. Cephalad of the fissure of Sylvius, it may be traced from the lateral inferior border of the frontal lobes, where the arachnoid of the base and the arachnoid of the convexity are continuous, over the orbital surface of the frontal lobes to the *great interhemispherical fissure* into which it passes to become continuous with the arachnoid of the convexity. In its course across the frontal lobe, the arachnoid conforms to the dural pocket in which is lodged the tip of the olfactory lobe. Caudad, however, the arachnoid passes across the olfactory tracts.

In the middle third of the brain, as the arachnoid of the convexity approaches the lateral inferior border of the temporal lobes and the temporal pole, it leaves its intimate relationship with the pia and stretches cephalically over the stem of the Sylvian fissure to become continuous with the arachnoid of the frontal lobes. Mesially, the arachnoid detaches itself from the summit of the temporal lobe and passes directly across the base of the brain to the corresponding point on the opposite temporal lobe, thus forming a somewhat voluminous space in the vicinity of the optic chiasm, the floor of the third ventricle and the peduncular region.

In the midline, after supplying a sheath to the infundibulum, the arachnoid passes cephalically from the vicinity of the optic chiasm into the great longitudinal fissure, there becoming continuous with the arachnoid of the convexity, its superior surface in contact with the inferior free border of the falx cerebri. If traced caudad the mesial portion of the basilar arachnoid comes into relationship with the *peduncles* as they emerge from the base of the brain and, surrounding them rather loosely, it is continued downward around the *pons* and the *bulb*.

The Arachnoid of the Convexity. The arachnoid of the convexity is continuous with the arachnoid of the base at the infero-lateral margin of the frontal, temporal and occipital lobes. Cephalad at the frontal pole, and caudad at the occipital pole, the arachnoid of the base becomes continuous with the arachnoid of the convexity. Traced upward over the frontal, parietal and occipital lobes, the arachnoid passes over the entire convexity of these lobes and reaches their superior border, the lip of the *great longitudinal fissure*. The membrane passes down into this fissure for a variable distance. Reaching the lowest limit of the dural reduplication, the arachnoid leaves the surface of the convexity and passing across ventral to the inferior free margin of the falx cerebri, meets its fellow of the opposite side. Thus is formed a subarachnoid space lying dorsal to the corpus callosum which

decreases in size from before backward. From the splenium, the arachnoid passes around the free border of the tentorium and then spreads out over the colliculi and the tentorial surface of the cerebellum. The membrane then reaches the summit of the cerebellum and passing to the inferior vermis it bridges the angle between the inferior surface of the cerebellum and the dorsal surface of the bulb. Traced laterally, the arachnoid passes over the hemispheres of the cerebellum and then forward to become continuous with the arachnoid surrounding the cerebral peduncles and the pons. From the lateral inferior border of the occipital lobes, it passes mesially to the arachnoid covering the cerebral peduncles.

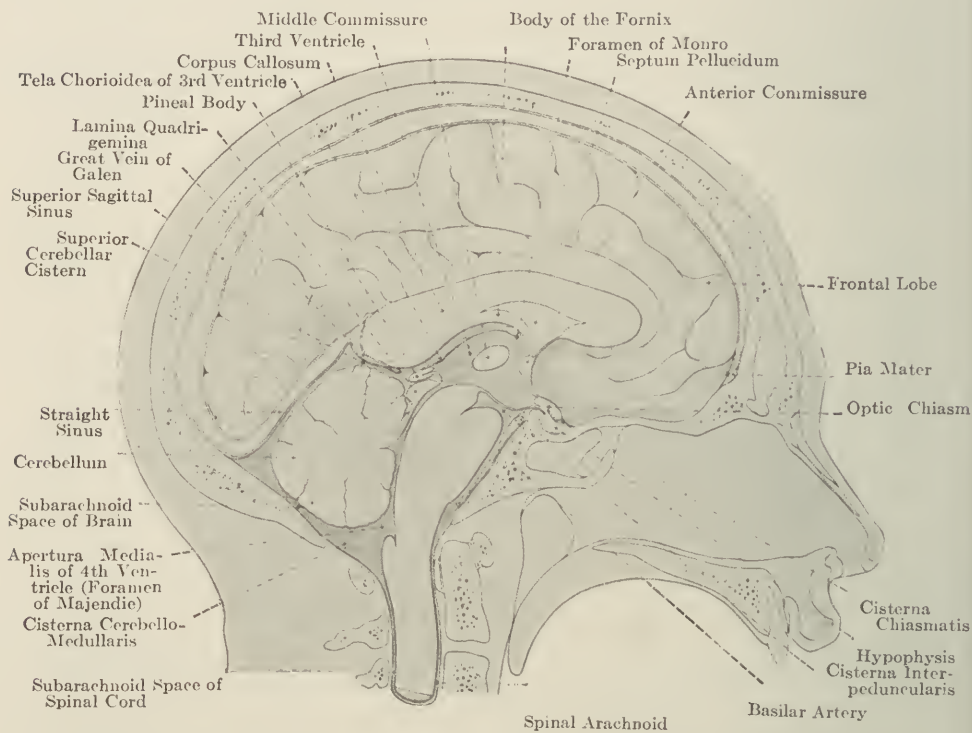


FIG. 475.—The subarachnoid spaces in a median section of the head, left half, viewed from the right. The falx cerebri has been removed. (*Spalteholz.*)

The membrane throughout the greater part of the convexity lies in contact with the summits of the convolutions, passing across them without dipping downward into the sulci.

The System of the Arachnoidal Cisterns. The close relationship between arachnoid and pia mater in certain locations ceases to exist, and by the separation of these two membranes, spaces; more or less voluminous according to the physical conformation of the structures which cause them, come into existence. These spaces form a series of cisterns which may be most advantageously followed from behind forward. As the arachnoid passes upward from the vertebral canal it lies in more or less intimate

contact with the bulb. As the cerebellum is approached, however, the arachnoid begins to be less closely applied to the neuraxis throughout its entire circumference. This separation is most extensive dorsally where the arachnoid passes from the bulb to the summit of the cerebellum. This space, called the *cisterna cerebello-medullaris*, is limited above by the inferior vermis and the mesial portions of the hemispheres, dorsally and laterally by the arachnoid, and ventrally by the inferior medullary velum and the tela chorioidea inferior. The cistern is particularly important because the cerebrospinal fluid formed within the ventricular system of the brain empties into the *cisterna cerebello-medullaris*. This cistern is also known as the *cisterna magna*.

Lateral to the *cisterna cerebello-medullaris*, the arachnoid rather closely approaches the lateral surface of the pons, but ventrally it again separates from the pons, leaving a space called the *cisterna pontis*. This cistern, together with those continuous cephalically with it, forms the great water-bed of the brain.

As the arachnoid passes over the cerebellum it is in intimate relationship with that structure at its summit. But as the tentorial surface of the cerebellum is approached, the arachnoid leaves the superior vermis and forms the *cisterna superior*. Then bridging over the colliculi, it approaches the free edge of the tentorium forming the *cisterna colliculorum*. Ventrally, as the cephalic limit of the pons is reached, the arachnoid passes further from the surface of the cerebral peduncles and becomes attached laterally to both temporal lobes. This separation produces a deep and extensive space which may be divided into a number of secondary spaces. In the midline and corresponding to the deep cleft between the diverging cerebral peduncles is located the *cisterna interpeduncularis*, and on either side between the ventral surface of the peduncle and the visceral layer of the arachnoid lies the *cisterna lateralis*.

At the temporal poles, the arachnoid swings across the stem of the Sylvian fissure to reach the orbital surface of the frontal lobe and in so doing forms a moderately large arachnoid space. This space has been called the *cisterna fissuræ Sylvii*. Still further cephalad, the median portion of the basilar arachnoid passes over the optic chiasm, and the space thus formed is the *cisterna chiasmatis*. Continuing still further cephalad and running upward from the *cisterna chiasmatis*, the arachnoid is still separated from the underlying brain tissue and in this region the space is called the *cisterna laminae terminalis*.

In the great longitudinal fissure, the arachnoid passes across from side to side at some distance from the corpus callosum, and the space thus formed between the arachnoid, which is in contact with the inferior free border of the falx cerebri and the corpus callosum, is called the *cisterna corporis callosi*.

The only prolongation formed by the arachnoid is that found about the optic nerves as they pass forward to the eyeball. These nerves are surrounded by special compartments of the subarachnoid and subdural spaces.

Throughout the entire system of cisterns, these spaces are crossed in

all directions by delicate strands of arachnoid tissue. The spaces are completely filled by the cerebrospinal fluid and traversed by the vessels passing to and from the brain. They assume diagnostic importance through the presence within them of the nerves which enter and leave the axis. The access thus provided for infection to the cranial nerves explains the early incidence of cranial nerve palsies in the course of basilar meningitis.

The Pacchionian Granulations. Since the subarachnoid space is a closed cavity filled with the cerebrospinal fluid, which is constantly being secreted by the chorioidal glands some means of egress must be furnished for the fluid. This exit is provided by a system of filters called the *Pacchionian bodies* or *granulations* which are formed by reduplication and thicken-

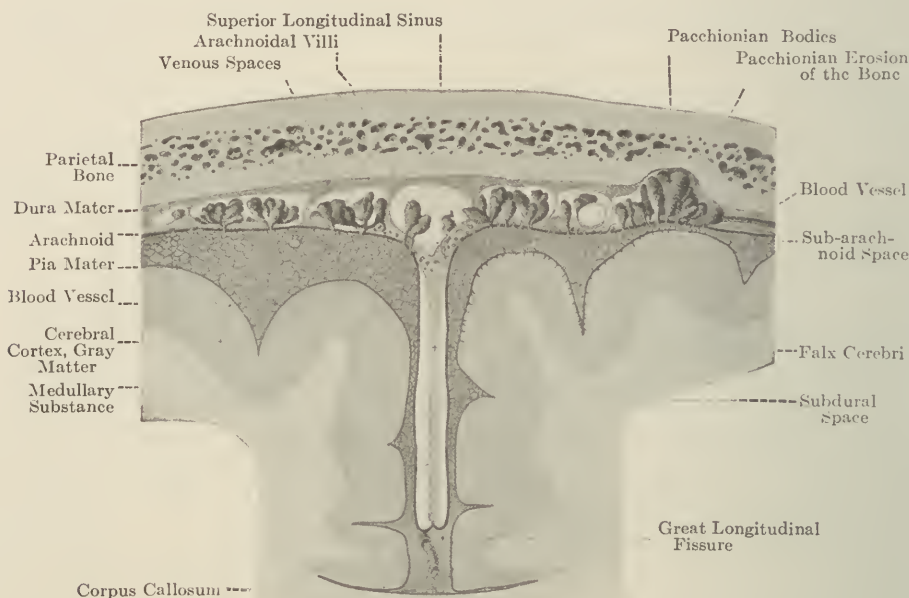


FIG. 476.—Frontal section through the skull, meninges and brain. (*Spaltholz*.)

ings of the arachnoid. These bodies are located in the vicinity of the great parietal sinuses of the dura mater, the *superior longitudinal sinus*, the *lateral sinus*, the *superior petrosal* and *cavernous sinus*, also along the large branches of the *middle meningeal vein* and at the junction of the *great vein of Galen* and the *straight sinus*. They vary in shape, being spherical, ovoid, fusiform, sessile or pedunculated. In size they vary from one to fifteen millimeters. Before their true function was appreciated, they were variously interpreted as senile growths, fringes of the arachnoid, lymphomata, and other forms of pathological growths. By certain authors, the granulations were supposed to supply a ligamentous support to the brain, keeping it from contact with the base of the skull. With the appreciation

of the cerebrospinal circulation, however, their functions took on a new significance and they are now recognized as the structures through which the fluid makes its way into the general circulation.

The granulations are invaginated into the cavity of the sinus or of the parasinoidal lacunæ, the blood lakes which lie at either side of the sinus between the two layers of the dura. As invaginations, they are still covered by the outer layer of the arachnoid and the inner layer of the dura. The subdural space over their summits is obliterated and the two layers, the arachnoid and the dura mater, fuse.

The larger granulations form indentations on the inner table of the skull. Occasionally the granulations may attain such size as to erode the inner

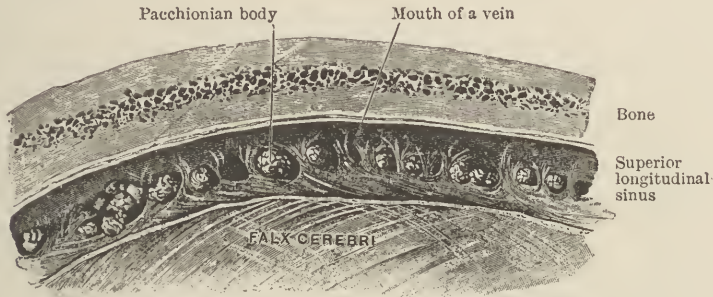


FIG. 477.—Mesial section through the cranial vault in the frontal region. Displays a portion of the superior longitudinal sinus and the Pacchionian bodies protruding into it (enlarged). (*Cunningham.*)

table and rest in the diploë or lie beneath the epicranium, when they may form small pulsating herniæ. They increase as age advances, being absent in the infant and becoming progressively more numerous in the aged. They are more numerous in males than in females. Their internal structure consists of a fine reticulum whose spaces are continuous with the subarachnoid space and consequently filled with the cerebrospinal fluid. Since the intrathecal pressure of the cerebrospinal fluid is greater than the venous pressure within the dural sinuses, an immediate osmosis or filtration may take place through the attenuated arachnoid and dura mater into the blood stream within the sinuses.

The Minute Structure of the Arachnoid. The minute structure of the arachnoid is simple, consisting of two layers of flat endothelial cells in contact with the dura mater externally and the pia mater internally. Between these two layers of cells there is a delicate layer of connective tissue which is formed by interlacing strands of white fibrous and yellow elastic tissue, between which are found many connective tissue cells. There are no blood vessels in the arachnoid, its nutrition being supplied by the cerebrospinal fluid in contact with its visceral surface and the lymph which lubricates the parietal surface. Numerous lymph channels and spaces have been described in the intra-arachnoid tissue. Nerve filaments have also been described within the arachnoid. At the points where the arachnoid

becomes fused with the pia mater, the endothelial layer ceases and the connective tissue of the two membranes is fused together.

THE CEREBROSPINAL FLUID

The cerebrospinal fluid covering of the brain is in all particulars identical with the fluid as described under the coverings of the spinal cord.

The circulation of the fluid seems to follow certain definite channels. From the ventricular cavity, it finds a means of escape into the subarachnoid space through three foramina situated in the roof of the medullary portion of the fourth ventricle. These are the *foramen of Magendie*, which is a single opening located just cephalad of the obex, and two foramina, the *foramina of Luschka* or the *foramina of Retzius and Key*, which are situated in the lateral recesses of the fourth ventricle. The fluid emerges into the cisterna cerebello-medullaris and passes downward along the dorsal aspect of the vertebral canal. This canal is incompletely divided into a dorsal and a ventral compartment by the *ligamentum denticulatum*. At the lower extremity of the cord the fluid fills the rest of the subarachnoid space over the *cauda equina* and then passes upward on the ventral aspect of the cord in front of the ligamentum denticulatum. The fluid flows through the foramen magnum into the skull, spreads out over the convexity of the brain, and finally reaches the venous circulation through the intermediation of the Pacchionian granulations.

THE PIA MATER

The *pia mater* is the most internal of the coverings of the brain. Although it is in contact and fused with the central nervous system, yet it is everywhere excluded from contact with the essential active ectodermal tissue by a thin layer of neuroglia called the *membrana limitans gliae* which at all points encloses the central nervous tissue. The connection of the pia mater with the nervous system is made even more intimate by the blood vessels which pass to and fro between the membrane and the brain. In the pia mater occur the main divisions of the arteries of the brain which then pass into the nervous system accompanied by a delicate sheath of connective tissue derived from the pia mater. This sheath continues for a short distance into the brain substance and then becomes lost in the adventitial tissue of the arteries. The pia mater is the true nutritive covering of the central nervous system, for it conveys the blood vessels derived from the larger trunks situated in the subarachnoid space.

The pia mater is adherent to the underlying nervous system by fine trabeculae of connective tissue. This adherence is not so intimate as that encountered in the spinal pia mater. Over the convexity the pia mater is readily removable, but even here a hasty attempt to strip it from the brain tissue will result in small pieces of cortical material being torn out with the entering and emerging blood vessels. The pia mater follows all the inequalities of the surface configuration of the brain, descending into the

sulci and fissures and lining them to the very bottom of these depressions, with the single exception of the cerebellum, where the membrane passes over the summits of the folia without passing into the sulci. It is most adherent in the vicinity of the *fissure of Bichat*, which lies between the temporal lobes and the cerebral peduncles, and over the *rhombencephalon*, where it begins to assume the characteristics of the spinal pia mater.

The Chorioidal Glands. Beneath the splenium of the corpus callosum the pia mater is invaginated over the roof of the third ventricle and assists in the formation of that structure. In this region the pia mater becomes thickened and is invaded by masses of capillaries. The endothelium lying over these capillary knots becomes modified and there results the formation of the chorioidal glands which secrete the spinal fluid. The mesial continuation of the fissure of Bichat is carried upward over the roof of the third ventricle, while its lateral portions pass into the hippocampal fissure. The pia mater follows the fissure of Bichat, forming in the ventricular roof the *chorioid gland* of the *third ventricle*. Laterally, where it approaches the choroid fissure, it enters the descending horn of the lateral ventricle, pushing a layer of ependyma before it to form the *chorioid gland* of the *temporal horn* of the *lateral ventricle*. The chorioid gland hangs from the roof like a bunch of grapes, suspended on each side of the median line within the cavity of the third ventricle. In this region also, as is the case with all of the chorioidal glands, it is covered by a layer of ependyma. The fusion of the pia mater with the ependyma forming the roof of the third ventricle is called the *tela chorioidea* of the *third ventricle*. The tela chorioidea is triangular, with its base situated caudally under the splenium of the corpus callosum. Its lateral borders are attached along the *tenia semicircularis* on each side. The apex of the tela chorioidea is located caudal to the anterior pillars of the fornix where the invagination of the pia enters the body of the lateral ventricle.

In the region of the fourth ventricle, the pia mater fuses with the ependyma forming the caudal portion of the ventricular roof below the inferior medullary velum. It fills in the triangular space limited above by the inferior medullary velum, laterally by the lateral limiting walls of the fourth ventricle, and caudally by the obex. In this region the pia mater and ependyma are invaginated into the cavity of the fourth ventricle as two chorioidal glands situated one on either side of the midline, the *chorioidal glands of the fourth ventricle*. This invagination is continued upward under the inferior margin of the inferior medullary velum, and the two plexuses, becoming divergent, pass into the lateral recesses of the ventricle.

Communications Between the Ventricular Cavity and the Subarachnoid Space. In the roof of the fourth ventricle are located the three openings by which the cavity of the ventricular system is placed in continuity with the subarachnoid space. These three foramina are located as follows: An unpaired opening called the *foramen of Magendie* is placed just cephalad of the obex where the lateral borders of the fourth ventricle begin to diverge. The other two form a pair, one in either lateral recess of the fourth ventricle, and are called the *foramina of Retzius and Key* or the *foramina of Luschka*.

The continued patency of these foramina is essential to the maintenance of the integrity of the central nervous tissue, for closure of them results in a failure of escape of the cerebrospinal fluid from the ventricular cavity and thus produces an *internal hydrocephalus*.

Minute Structure of the Pia Mater. The pia mater consists of a single layer of endothelial cells lying upon a delicate layer of connective tissue formed of interlacing bundles of white fibrous and yellow elastic tissue, in the meshes of which are interspersed many round, branching and fusiform connective tissue cells. The pia mater is extremely vascular and many vessels of all sizes are found within its meshes.

The presence of lymphatics in the pia mater is uncertain, some authors claiming that they are present, others denying their existence.

THE BLOOD VESSELS OF THE CRANIAL MENINGES

The Vessels of the Pia Mater. The nutrition of the pia mater is maintained by small branches derived from the vessels which are passing through that membrane to enter the central nervous system. The venous drainage follows the same arrangement; small pial veins joining the vessels which emerge from the central nervous system, pass through the pia mater and empty into either the dural sinuses or the meningeal system of veins. The needs of the arachnoid are supplied by the cerebrospinal fluid and its nutrition is carried on by direct imbibition of the fluid.

The Arteries of the Dura Mater. For the nutrition of the dura mater and the cranium a separate system of vessels is provided called the meningeal vessels. These vessels arise from a number of sources and enter the dura through the basilar foramina.

In the anterior cranial fossa are one or two small arteries which arise from the *anterior* and *posterior ethmoidal arteries* before they pass through the anterior and posterior ethmoidal foramina. These small vessels ramify in the dura mater lining the floor of the anterior cranial fossa, and also enter the beginning of the falx cerebri. They are called the *anterior meningeal arteries*.

In the middle fossa of the skull, there enter the dura, the *middle* and the *small meningeal arteries*. The middle meningeal artery is a branch of the internal maxillary artery arising from that vessel between the external pterygoid muscle and the sphenomandibular ligament. It passes upward between the two roots of the auriculotemporal nerve and enters the cranial cavity through the *foramen spinosum*, behind and lateral to the mandibular branch of the trigeminal nerve. It is accompanied by two *venæ comites* which drain into the pterygoid plexus of veins. In the middle fossa, the artery passes forward and upward in a groove, which may be a canal in the greater wing of the sphenoid, to divide into *anterior* and *posterior* branches. During its course the middle meningeal artery gives off the following branches:

(a) Petrosal—to the tympanic cavity through the hiatus Fallopii.

(b) Gasserian—minute branches to the ganglion and the roots of the trigeminal nerve.

(c) Tympanic—to the tympanic cavity through the foramen for the tendon of the tensor tympani.

(d) Orbital—to the orbit through the foramen lacerum anterius.

(e) Anterior terminal—this is the larger of the two terminal meningeal branches. It passes upward along the greater wing of the sphenoid to the anterior inferior angle of the parietal and then upward behind the parieto-frontal suture almost to the vertex dividing into many subsidiary branches which pass to the dura and the cranial bones.

(f) Posterior terminal—this vessel passes backward and upward from the greater wing of the sphenoid to the squamous portion of the temporal bone and thence to the parietal bone, over which it ramifies in the dura, supplying it and the cranium.

The *small meningeal artery* is an inconstant artery and arises also from the internal maxillary artery, a few millimeters internal to the origin of the middle meningeal. It passes upward on the inner surface of the external pterygoid muscle and enters the middle fossa of the skull through the foramen ovale in company with the mandibular branch of the trigeminal nerve. It is distributed to the mesial portion of the dura mater, the Gasserian ganglion and the walls of the cavernous sinus, and anastomoses with the middle meningeal and internal carotid arteries.

There are also *meningeal branches* from others of the vessels derived from the external carotid:

(a) The meningeal branches of the occipital artery. The number of meningeal branches from the occipital artery is variable. They enter the cavity of the skull through the anterior condyloid foramen in company with the hypoglossal nerve or through the jugular foramen. These branches ramify in the dura surrounding the foramina and supply the upper part of the internal jugular vein, the lateral sinus and the dura of the posterior fossa. They anastomose with branches of the middle meningeal and the meningeal branches of the ascending pharyngeal artery.

(b) The meningeal branches of the vertebral artery. In the posterior cranial fossa are located the *posterior meningeal arteries*, one on each side, which arise from the vertebral arteries just after they have pierced the dura and are distributed to the dura of the posterior fossa.

(c) The meningeal branches of the ascending pharyngeal artery. The number of these branches is variable. They enter the cranial cavity through the foramen lacerum posterius, the anterior condyloid foramen and the foramen lacerum medium. They supply the dura in the immediate vicinity of these foramina and anastomose with the meningeal branches of the middle meningeal and the vertebral arteries.

(d) Additional meningeal branches which are more or less constant may supply the dura of the cranial cavity, as:

1. The mastoid artery through the mastoid foramen.
2. The anterior condyloid artery through the anterior condyloid foramen.

3. The parietal artery through the parietal foramen.
4. Small branches from the internal carotid within the cavernous sinus which pass to the walls of the cavernous sinus.
5. Branches from the middle cerebral artery to the dura in its vicinity.
6. Branches from the ophthalmic artery.
7. Branches from the lachrymal artery.
8. Branches from the stylo-mastoid branch of the posterior auricular.

The Veins of the Dura Mater. The meningeal veins arise through the confluence of capillaries which lie in the dura. Except in the case of the middle meningeal, they do not accompany meningeal arteries, but develop regionally and empty into the *dural sinuses*. They often terminate in the *lacunæ* which lie along the dural sinuses between the two layers of the dura, or they may join the *diploic system* of veins. The middle meningeal artery is accompanied by a pair of *venæ comites* which arise from the territory supplied by the middle meningeal artery. These veins lie on either side of the artery and are connected by many cross anastomoses so that they overlie and partially hide the artery.

The *dural veins* are arranged in two plexus one in each layer of the dura mater. The deep plexus situated in the inner layer of the dura is but little developed and drains into the superficial plexus which is located in the outer layer of the dura. This plexus forms regional veins which, with the exception of the *venæ comites* of the middle meningeal, do not follow the arteries, but empty into the *dural sinuses*. The majority of the meningeal veins empty into the *superior longitudinal sinus*, but a few veins arising in the lower parts of the meninges open below into the *pterygoid plexus* of veins.

Communications between the intra- and extra-cranial vessels are afforded by means of large anastomotic channels which act as safety valves for the intracranial circulation. According to the local conditions of pressure, the flow in these vessels may be in either direction. The meningeal veins are not provided with valves.

THE LYMPHATICS OF THE MENINGES

This whole question is still in a controversial state. Some investigators have discovered spaces which are lined with endothelium and resemble in all respects lymphatics in all of the membranes, while other investigators deny their existence. It seems well established that the subdural space is a lymphatic space, that it is continuous with the perineural lymph spaces found in the nerves, and that the fluid present in it is true lymph; but the question of the identification of true lymphatics in the membranes of the brain must await further study.

THE NERVES OF THE MENINGES

The presence of nerve fibers in the arachnoid and pia mater has been claimed by some investigators, but this has not been substantiated.

The dura mater is supplied by a number of sensory nerves. In the anterior fossa, the *nasal branch* of the *ophthalmic* division of the *trigeminal nerve* supplies certain dural branches, which ramify in the dura of the anterior cranial fossa, especially to that portion covering the cribriform plate of the ethmoid.

Laterally there are rather extensive branches, which arise from the *Gasserian ganglion* and from the *mandibular nerve* near its origin, which can be followed all the way to the superior longitudinal sinus. Communications have been demonstrated between these branches and filaments derived from the *sympathetic plexus* about the middle meningeal artery.

The tentorium is supplied by the *recurrent nerve of Arnold* which arises from the ophthalmic division of the trigeminal nerve near its entrance into the orbit. This nerve passes backward in contact or fused with the trochlear nerve. Reaching the tentorium it ramifies within it, dividing into two sets of fibers, the *mesial branches*, which pass toward the straight sinus, and the *lateral branches*, which pass outward toward the lateral sinus.

From the ganglion of the root of the vagus nerve is given off a *recurrent branch* which passes upward through the jugular foramen to supply the dura mater of the posterior fossa of the cranium, especially in the vicinity of the lateral and occipital sinuses.

One or two filaments are also given off from the *hypoglossal nerve* which supply the dura mater of the posterior cranial fossa and the diploë of the occipital bone. Considering the fact that the hypoglossal nerve is a purely motor nerve, it is probable that these sensory branches are derived from the loop between the hypoglossal and the first and second cervical nerves.

Nerve fibers which arise in the *sympathetic system* also find their way in considerable numbers into the cranial cavity along the plexus which accompany the middle meningeal artery, the internal carotid and the plexus about the cavernous sinus. It is questionable, however, whether any of these fibers are sensory in character.

CHAPTER XL

THE ENDBRAIN

THE CRANIO-CEREBRAL CIRCULATION

THE ARTERIAL CIRCULATION OF THE BRAIN

General Arrangement of the Arterial Circulation. The arrangement of the blood vessels which constitutes the mechanism by which nutritive substances are carried to and waste products removed from the nervous system, can be most advantageously studied by considering the various arteries and veins which are associated with each division of the central nervous system. This plan has previously been adhered to in the description of the various parts of the brain and spinal cord, while in the following description the circulation may be viewed in its entirety.

Upon examining the circulation of the brain, one is impressed by two obviously opposing details of its construction, namely, the efficiency of the system for conducting the blood into the skull, and the mechanical deficiency of vascular distribution within the brain. Nowhere in the entire body has evolution produced a more effective vascular mechanism than that presented in the *circle of Willis*. From this circle arise the main channels designed for the blood supply of the brain. At each of the four corners of this so-called circle is situated an artery of sufficient caliber to maintain alone the integrity of the cerebral circulation. From this circle the substance of the brain receives intrinsic arteries which are distributed to different regions of the brain anastomosing with other vessels about the periphery of these regions. There is no anastomosis between the smallest brain arteries. If one of these is obstructed there is no further possibility of reestablishing the circulation, and the part of the nervous system supplied by the affected vessel undergoes degenerative changes.

THE CIRCLE OF WILLIS

The foundation of the cerebral circulation is the circle of Willis, which consists of a vascular ring in the form of a hexagon or heptagon situated at the base of the brain. This circle is formed cephalically by three vessels, the *anterior communicating artery* mesially and the two *anterior cerebral arteries* laterally. Its lateral portion is continued caudally on both sides by the *posterior communicating arteries*, and it is completed caudally by the two *posterior cerebral arteries* which arise from a common stem, the *basilar artery*. The circle is supplied by four tributary arteries. At the cephalo-lateral angles are situated the *internal carotid arteries*, one on each side.

Caudally it is supplied by the two *vertebral arteries* which arise from the basilar artery. The circle of Willis is located in the *optico-peduncular space* on the base of the brain; its caudal portion, formed by the division of the basilar artery into the two posterior cerebrals, lies upon the cerebral peduncles as they converge to enter the pons. Its lateral components, the posterior communicating arteries, pass forward across the mesial edge of the cerebral peduncles to the point of origin of the *stem of the Sylvian fissure*, where they meet the internal carotid arteries.

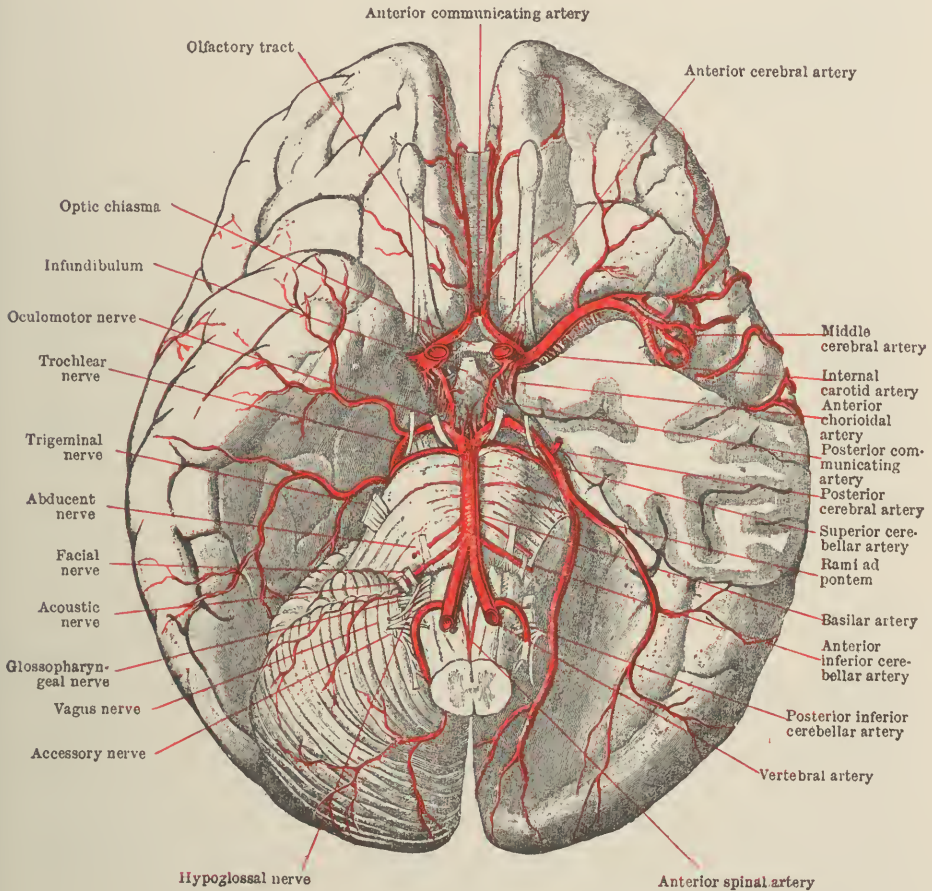


FIG. 478.—The arteries of the base of the brain. The circulus arteriosus. (Willis.)

The cephalic derivatives of the circle, the *anterior cerebral arteries*, cross the olfactory trigone and converge toward the beginning of the *great longitudinal fissure* of the brain. The circle is completed cephalically by an unpaired vessel, the *anterior communicating artery*, which joins the anterior cerebral arteries in the depth of the great longitudinal fissure. It thus embraces from before backward the optic chiasm, the infundibulum, the tuber cinereum, the corpora mammillaria and the posterior perforated space.

While the circle of Willis determines the circulation of the hemispheres and base of the brain, the other portions of the brain-stem and the cerebellum receive their blood supply from vessels which ultimately contribute to the formation of the circle of Willis.

The Tributaries of the Circle of Willis. THE VERTEBRAL ARTERIES. These arteries, the first branch of the subclavian artery on each side, arise from the upper and dorsal portion of the parent stem between the scalenus anticus and the longus colli muscles.

The course of each artery may be divided into four portions:

The *first portion* of the vertebral artery passes upward and backward between the scalenus anticus muscle and the outer border of the longus colli muscle to the foramen in the transverse process of the sixth cervical vertebra which it enters.

The *second portion* of the artery lies within the foramina of the cervical vertebræ from the sixth cervical vertebra to the atlas where it enters upon the third portion of its course.

The *third portion* of the course of the vertebral artery extends from the foramen in the transverse process of the atlas to the point where the artery enters the vertebral canal. Its course is tortuous; emerging from the foramen in the transverse process of the atlas, it passes between the anterior primary division of the suboccipital nerve mesially and the rectus capitis lateralis muscle laterally, then horizontally backward and inward around the superior articular process of the atlas in a groove on the dorsal arch of the atlas, the *sulcus arteriæ vertebralis*, but separated from contact with the bone by the suboccipital or first cervical nerve.

The *fourth portion* of the artery extends from its entrance into the vertebral canal to the point where it unites with its fellow of the opposite side to form the *basilar artery*. Almost immediately upon entering the vertebral canal, the vertebral artery pierces the dura and passing upward and forward about the lateral surface of the spinal cord between the roots of the hypoglossal nerve ventrally and the first denticulation of the ligamentum denticulatum dorsally, it passes through the foramen magnum and enters the cranial cavity. During its course about the spinal cord, the artery enters and traverses the arachnoid and, gaining the subarachnoid space, passes gradually upward and inward to the middle of the caudal border of the ventral surface of the pons where it meets and anastomoses with its fellow of the opposite side to form the *basilar artery*.

It is not unusual to find the vertebral arteries of unequal size. In fact, at times the vertebral artery of one side may fail to appear, in which case the remaining vertebral artery becomes the basilar artery at the caudal limit of the pons.

BRANCHES OF THE VERTEBRAL ARTERY. *First Portion*—A few muscular twigs.

Second Portion—(a) Muscular branches varying in size and number, which supply the deep muscles of the neck and anastomose with the deep cervical, ascending cervical and occipital arteries.

(b) *Spinal branches* arise from the mesial surface of the artery, pass through the intervertebral foramina and divide into twigs which extend along the roots of the cervical nerves to reinforce the ventral and dorsal spinal arteries.

Third Portion—(a) *Muscular branches* to the muscles in the suboccipital region.

(b) *Anastomotic branches* unite with branches from the princeps cervicis, the occipital and the deep cervical arteries.

Fourth Portion—(a) *Meningeal Branches*. These may be one or two in number and variable in size. They pierce the dura and ascend into the posterior fossa to supply the dura lining that cavity. They anastomose with the meningeal branches of the occipital, the ascending pharyngeal and the middle meningeal arteries.

(b) *Dorsal Spinal Artery*. This vessel arises after the vertebral artery has pierced the dura and passes downward along the dorso-lateral aspect of the medulla and spinal cord in front of the origin of the dorsal nerve roots. It is a slender artery, which by means of segmental reinforcements is continued for a variable distance along the spinal cord. It provides branches to the pia mater and presents a more or less regular series of anastomoses with its fellow of the opposite side across the dorsal aspect of the medulla and spinal cord. It may terminate by ending in the ventral spinal artery.

(c) *Ventral Spinal Artery*. This vessel, larger than the dorsal spinal artery, arises near the termination of the vertebral artery and passes obliquely downward and inward to anastomose with its fellow of the opposite side to form a vessel which lies in the ventro-median sulcus of the medulla and spinal cord and extends to the lowest limit of the spinal cord. It is reinforced by segmental branches from the vertebral, intercostal, lumbar and sacral arteries. It may receive the termination of the dorsal spinal artery at any point in its course. It supplies branches to the pia mater and to the spinal cord.

(d) *Posterior Inferior Cerebellar Artery*. This is the largest branch of the vertebral artery and arises a short distance below the pons. It passes obliquely backward around the lateral surface of the medulla between the roots of the hypoglossal nerve, and then between the spinal accessory and vagus nerves to the *vallecula* of the cerebellum, where it divides into lateral and mesial terminal branches. From the artery, before its terminal division, arise branches which supply the medulla and the chorioid plexus of the fourth ventricle. The mesial terminal or *vermal branch* passes backward over the inferior vermis and the lateral lobe of the cerebellum supplying chiefly the vermis, and finally anastomoses with its fellow of the opposite side. The lateral or hemispherical branch passes outward and ramifies over the occipital surface of the cerebellar hemisphere and anastomoses with the superior cerebellar artery.

THE BASILAR ARTERY. This artery is formed by the confluence of the two vertebral arteries at the middle of the caudalmost fibers of the pons. In case either of the vertebral arteries is missing, the continuation of the

remaining vertebral artery becomes the basilar artery at this point. The artery terminates at the upper border of the pons by dividing to form the two *posterior cerebral arteries*. It is of moderate size and lies in a groove on the ventral surface of the pons, separating the pons from the basi-occipital and basi-sphenoid bones. It is situated between the two abducens nerves as they course upward and forward toward the triangular space between the two terminations of the borders of the tentorium. As it passes upward, the basilar artery gives off a number of slender vessels which pass laterally almost at right angles to the parent stem.

Branches of the Basilar Artery. (a) *Transverse Branches.* These consist of a set of small arteries which pass transversely outward and curve around the lateral surfaces of the pons, supplying the pons, the middle cerebellar peduncle and the roots of the trigeminal nerve. These branches vary in number and size.

(b) *Auditory Branches.* A pair, one on each side, of long, slender branches accompanies the seventh and eighth nerves to the internal auditory meatus, into which it passes to reach the lamina cribrosa and aid in the supply of the internal ear.

(c) *Anterior Inferior Cerebellar Arteries.* These vessels, one on each side, arise at about the middle of the course of the artery and pass backward to the caudal portion of the petroso-ventricular surface and the occipital surface of the hemispheres of the cerebellum over which they ramify to supply these areas and to anastomose with the posterior inferior cerebellar arteries.

(d) *Superior Cerebellar Arteries.* These vessels also arise one on each side, from the basilar artery near its termination and proceed outward at the cephalic limit of the pons. Passing around the crus cerebri caudal to the fourth cranial nerve, they reach the tentorial surface of the cerebellum where each artery divides into a lateral and a mesial terminal branch. The mesial branch supplies the superior vermis and the superior medullary velum. The lateral branch is distributed over the tentorial surface of the cerebellar hemispheres and anastomoses with the posterior inferior cerebellar artery.

(e) *Posterior Cerebral Arteries.* These arteries are produced by the division of the basilar artery. They arch backward and upward between the crus cerebri and the uncinate convolution, and pass parallel to the superior cerebellar arteries from which they are separated by the third and fourth cranial nerves, as these pass forward toward the cavernous sinus.

Branches of the Posterior Cerebral Arteries. (1) *Ganglionic or Central Branches.* These arteries arise in three sets as the posterior cerebral arteries pass over the posterior perforated space.

(i) The *postero-mesial ganglionic arteries* which pass to the inner side of the crus cerebri and entering the posterior perforated space supply the crus cerebri, the posterior portion of the optic thalamus, the corpora mammillaria and the walls of the third ventricle. Accessory arteries arise from the posterior cerebral arteries, penetrate the crus cerebri and terminate in the substantia nigra.

(ii) The *postero-lateral set of ganglionic branches*, which pass around the lateral aspect of the crus cerebri and supply the colliculi, the brachia, the pineal gland, the crus cerebri, the posterior part of the optic thalamus and the geniculate bodies.

(iii) The *posterior chorioidal set* of small vessels, which pass through the chorioidal fissure and enter the caudal portion of the chorioid plexus of the lateral ventricle.

(2) *Tentorial Branches*. These vessels pass to and supply the tentorium.

(3) *Posterior Communicating Arteries*. About one-half a centimeter from its origin, each posterior cerebral artery gives rise to a long slender artery which passes almost directly forward from the cephalic aspect of the posterior cerebral artery, diverging somewhat laterally and lying on the mesial half of the crus cerebri. These arteries pass forward and join the internal carotid artery just after its emergence from the roof of the cavernous sinus; or they may join either one of the derivatives of the internal carotid arteries, the anterior or middle cerebral arteries. The posterior communicating arteries form the lateral limbs of the circle of Willis. In their course forward from the posterior cerebral artery to join the internal carotid or one of its divisions, they give off a relatively large number of small branches which pass to and supply the uncinate convolution, the corpora mammillaria, the hypophysis, the posterior limb of the internal capsule, the crus cerebri, the optic tract and chiasm and the lamina terminalis. They vary greatly in size and may replace the posterior cerebral artery. Near the termination of the vessel each posterior communicating artery gives off a small vessel, the *anterior chorioidal artery*, which passes backward and outward between the crus and the uncinate convolution to the lower and front part of the chorioidal fissure, which it enters; it terminates in the chorioidal plexus of the temporal horn of the lateral ventricle.

(4) *Cortical Branches*. Passing backward, the posterior cerebral artery crosses beneath the splenium of the corpus callosum to the calcarine fissure, where it divides into its terminal branches. In its course it gives off:

(i) The *anterior temporal artery*, which is of variable constancy and size. It supplies the cephalic portions of the uncinate and occipito-temporal convolutions.

(ii) The *posterior temporal artery*, which is of greater size and constancy than the anterior temporal artery, and supplies the caudal part of the uncinate gyrus, the major portion of the occipito-temporal convolution and the lobulus lingualis.

(iii) The *calcarine artery*, which is one of the terminal branches of the posterior cerebral artery and is also its continuation along the calcarine fissure. It supplies the lobus cuneatus, the lobulus lingualis, and the dorsal part of the lateral surface of the occipital lobe.

(iv) The *parieto-occipital artery*, which is the other terminal branch of the posterior cerebral artery. It is smaller than the calcarine artery and passes to the cuneus and the precuneus.

(f) *Ganglionic Branches*. The branches of the basilar artery which enter the posterior perforated space can be divided into a median and a radicular

group. The median vessels pass into the interpeduncular space, penetrate the neuraxis, and terminate by being distributed to the central gray substance about the aqueduct of Sylvius and in particular supply the nuclei of the third and fourth cranial nerves. The radicular arteries pass outward toward the third and fourth cranial nerves and, upon meeting these structures, bifurcate into central and peripheral branches. The central branches accompany the radicles of the nerve to the nucleus of origin where they break up into a capillary plexus. The peripheral branches accompany the emergent nerves breaking up into a capillary plexus between the fibers of the nerve.

THE INTERNAL CAROTID ARTERIES. These arteries, together with the vertebral arteries, form the circle of Willis. They arise in the neck by the bifurcation of the common carotid to form the internal and external carotid arteries. The internal carotid is the larger of the two vessels and is placed slightly ventral and mesial to the external carotid. As it passes upward through the carotid and submaxillary triangles of the neck, it moves still more mesially until it lies mesial to the external carotid artery. It gives off no branches in the neck. Reaching the base of the skull it enters the carotid canal in the petrous portion of the temporal bone and, directed at first upward, then upward and inward, it emerges in the middle fossa of the skull, crosses through and over the cartilage filling in the foramen lacerum medium, and enters the floor of the cavernous sinus. It runs for a short distance within the sinus and then emerges from the roof, dividing into its terminal branches, the *anterior* and *middle cerebral arteries*. In its course it gives off the following branches:

1. In the temporal bone.

(a) *The Tympanic Branch.* This perforates the posterior wall of the carotid canal and anastomoses with a branch from the stylo-mastoid artery, and the tympanic branches of the internal maxillary artery and the ascending pharyngeal artery. These vessels together form the tympanic plexus which supplies the tympanum.

(b) *The Vidian Branch.* This small vessel accompanies the great deep petrosal nerve and anastomoses with the Vidian branch of the internal maxillary artery. It supplies branches to the upper part of the pharynx, the levator and tensor palati muscles and the Eustachian tube.

2. In the cranium.

(a) *Cavernous Branches.* These are small branches which pass to the walls of the cavernous sinus and to the third, fourth and ophthalmic division of the fifth and sixth cranial nerves.

(b) *Gasserian Branches.* These are small branches which pass to and supply the Gasserian ganglion.

(c) *Pituitary Branches.* These are small vessels which supply the pituitary gland.

(d) *Meningeal Branches.* These are small vessels which supply the dura of the middle cranial fossa and anastomose with the middle and small meningeal arteries.

(e) *Ophthalmic Artery.* This is a vessel of considerable size and arises from the cephalo-mesial surface of the internal carotid as that vessel turns

upward mesial to the anterior clinoid process. It passes forward and outward beneath the optic nerve, through the optic foramen in company with the optic nerve, and enters the orbit. The ophthalmic artery then passes along the lateral surface of the optic nerve in relation laterally with the ciliary ganglion and the external rectus muscle; then turning upward and inward between the optic nerve and the superior rectus muscle, it reaches the mesial wall of the orbit and terminates at the inner and front portion of the orbit by dividing into its terminal branches, the frontal and nasal arteries. In its course it gives off the following branches:

(1) *Posterior Ciliary Arteries.* These are small slender vessels, from six to eight in number, which pass along the sides of the optic nerve, pierce the sclerotic coat of the eyeball and terminate in the chorioid layer.

(2) *Central Artery of the Retina.* This vessel arises as the ophthalmic artery passes below the optic nerve, and entering the ventro-mesial surface of the nerve about twelve millimeters behind the sclerotic coat, it passes into the eyeball through the center of the disc and divides into its terminal branches which supply the retina.

(3) *Recurrent Branch.* This is a small branch which passes back through the sphenoidal fissure into the middle fossa. It anastomoses with the middle and small meningeal arteries and also with branches from the internal carotid and lachrymal arteries and supplies the dura mater.

(4) *Lachrymal Artery.* This vessel arises from the ophthalmic artery and passes to the upper and lateral angle of the orbit.

(5) *Muscular Branches.* There is an outer set of muscular branches to the upper and outer orbital muscles, and an inner set to the lower and inner orbital muscles. They anastomose with the lachrymal and supra-orbital vessels and also give off additional anterior ciliary vessels.

(6) *Supra-Orbital Branch.* This vessel is given off as the artery crosses below the optic nerve. It pierces the frontalis muscle and supplies the scalp, anastomosing with the superficial temporal and frontal arteries.

(7) *Ethmoidal Branches.* These are two in number, *anterior* and *posterior*, arising from the ophthalmic artery at the inner boundary of the orbit. The anterior ethmoidal artery accompanies the nasal nerve into the anterior fossa of the skull and then passing through the nasal slit into the nasal fossa it extends as far as the tip of the nasal cartilages. It supplies the dura mater, the anterior ethmoidal cells, the frontal sinus, the anterior and upper part of the nasal mucous membrane and the skin of the dorsum of the nose.

(8) *Palpebral Branches.* There are upper and lower sets of these branches to the upper and lower eyelids, anastomosing with the lachrymal, supra-orbital and infra-orbital arteries.

(9) *Nasal Terminal Branch.* This vessel leaves the orbit above the internal tarsal ligament, pierces the palpebral fascia and, supplying the skin in this region, anastomoses with the angular branch of the facial artery.

(10) *Frontal Terminal Branch.* This artery pierces the palpebral fascia at the upper and inner aspect of the orbit and in company with the supra-trochlear branch of the ophthalmic division of the trigeminal nerve, supplies

the anterior and mesial parts of the scalp. It anastomoses with its fellow of the opposite side and with the supra-orbital artery.

The ophthalmic artery is the nutritive artery of the orbital cavity, the globe of the eye and the retina. Its origin from the cerebral circulation emphasizes the original derivation of the eye from the neural tube, the visual organ retaining its primitive blood supply.

Terminal Branches of the Internal Carotid Artery. The *internal carotid artery* terminates by dividing into two large vessels which carry on the vascular supply of the median and anterior portions of the cerebral hemispheres. These vessels are the *anterior cerebral artery* and the *middle cerebral* or *Sylvian artery*. The latter is the larger of the two terminal branches.

A. Anterior Cerebral Arteries. These vessels, one on each side, complete cephalo-laterally the circle of Willis and by a small artery which affords communication between the two vessels in the ventral portion of the great longitudinal fissure, the *anterior communicating artery*, produce the closed ring of vascular channels which serves to equalize the circulation of the brain. The anterior cerebral artery passes forward and inward above the optic chiasm and traversing the lamina terminalis reaches the ventral origin of the great longitudinal fissure which it enters. At this point it is connected across the midline with its fellow of the opposite side by the anterior communicating artery. The anterior cerebral artery passing forward and upward, turns upward and backward around the *genu of the corpus callosum* and, lying then upon the dorsal surface of that mass of fibers, continues backward as far as the middle portion of the parietal lobe where it divides into its terminal branches. In its course it is at first distant from, but later in close association with, its fellow of the opposite side, and gives off the following branches:

(a) *Central or Ganglionic Branches.* These small vessels arise as the antero-mesial group of vessels in front of the optic chiasm and supply the rostrum of the corpus callosum, the lamina terminalis and the septum pellucidum. The anterior cerebral artery gives origin to a number of collaterals in the vicinity of the anterior perforated space which penetrate this layer of gray matter to end in the head of the caudate nucleus. These vessels are called the *anterior striate branches* of the anterior cerebral artery.

(b) *Cortical Branches.* (i) The *internal orbital branches*, which supply the internal orbital convolution, the gyrus rectus and the olfactory tract.

(ii) The *anterior internal frontal artery*, which may be double and is distributed to the anterior and lower part of the marginal convolution and the anterior portions of the superior and middle frontal convolutions.

(iii) The *middle internal frontal artery*, which supplies the posterior part of the marginal convolution and the upper portions of the superior and ascending frontal and ascending parietal convolutions.

(iv) The *posterior internal frontal artery*, which passes as far back as the quadrate lobule and supplies the corpus callosum, the quadrate lobe, and the upper part of the superior parietal lobule.

B. The Middle Cerebral or Sylvian Artery. This vessel, larger than the preceding, arises by the bifurcation of the internal carotid artery. Being the more direct continuation of the internal carotid, the middle cerebral artery is more often obstructed by emboli than is the anterior cerebral artery. It passes outward across the anterior perforated space to the Sylvian fissure, comparatively superficial at its beginning, then sinking more deeply into the deepening fissure. As it approaches its termination, it comes closer to the surface, finally emerging on the surface of the brain to divide into its terminal branches at the caudal extremity of the fissure. In its course it comes into intimate relationship with the island of Reil and actually divides into its terminal branches, the *parieto-temporal* and the *temporal arteries*, at the posterior limiting sulcus of Reil.

(a) *Central or Ganglionic Branches.* These branches are very numerous and quite irregular in number and distribution. They enter the anterior perforated space to supply the deeper structures of the brain. They are called the antero-lateral set of ganglionic branches. They may be divided into secondary sets.

(i) The *internal striate arteries* pass upward through the two inner segments of the lenticular nucleus and the internal capsule, the longest vessels ending in the caudate nucleus. They supply the anterior parts of the lenticular and caudate nuclei and the anterior limb of the internal capsule.

(ii) The *external striate arteries* pass upward through the lateral segment of the lenticular nucleus and between that nucleus and the external capsule. They divide into two sets, an *anterior lenticulo-striate* set, which traverse the lenticular nucleus and the internal capsule to end in the caudate nucleus, and the *posterior lenticulo-optic* group of arteries, which also pass through the lenticular nucleus and the internal capsule and terminate in the thalamus. One of the first set is the so-called *Charcot's artery of cerebral hemorrhage* and is the frequent source of extravasations which result in apoplexy.

(b) *Cortical Branches.* These arise as the Sylvian artery passes over the island of Reil in the following order:

(i) The *inferior external orbital artery* proceeds forward and outward to ramify over and supply the outer portion of the orbital surface of the inferior frontal convolutions.

(ii) The *ascending frontal artery* curves around the upper margin of the Sylvian fissure to pass over and supply the ascending frontal convolution of the lateral surface of the hemispheres and the caudal portions of the middle frontal convolution.

(iii) The *ascending parietal artery* passes along the caudal border of the ascending parietal convolution and supplies that gyrus and the superior parietal lobule.

(iv) The *temporal artery* passing out of the fissure over the temporal operculum, proceeds ventrally and caudally to supply the superior and middle temporal convolutions.

(v) The *parieto-temporal artery* continues the direction of the Sylvian artery and emerging from the fissure at its caudal termination supplies the inferior parietal lobule, the external occipital convolutions and the posterior part of the temporo-sphenoidal lobule.

The Arteries of the Convolutions. The ultimate distribution of the blood transported to the brain is mediated by the arteries of the convolutions. After the final divisions of the larger trunks, the smaller arterioles form irregular series of loops in the pia mater. From these loops there arise two sets of arteries which penetrate directly into the subjacent convolutions. These are the *long* and the *short arteries*. The former pass through the cortex and enter the medullary substance for a distance of three or four centimeters, giving origin to a rich capillary plexus. The short arteries penetrate into the cortex and immediately give origin to a rich capillary plexus in the substance of the gray matter. These vessels are terminal arteries, and the capillary plexus are confined to the territory of the artery from which they arise and do not connect with adjacent capillary plexus. The vessels as they leave the pia mater are accompanied for a short distance by a sheath of pia mater which gradually becomes lost by its merging with the adventitial sheath. The vessels are surrounded by lymphatic spaces, the continuation of the perivascular lymph spaces, which are called the *Virchow-Robin* spaces. The mesodermal elements are everywhere excluded from contact with the active ectodermal tissue by a thin layer of neuroglial tissue.

TABULATION OF THE ARTERIAL CIRCULATION FOR EACH AREA

MEDULLA AND PONS. Anterior spinal, vertebral, basilar and posterior cerebral arteries.

Nuclei of XII and bulbar XI—anterior spinal artery.

Nuclei of X, IX, VIII—vertebral and basilar arteries.

Nuclei of VII, VI, V—basilar artery.

Chorioid plexus of fourth ventricle—posterior inferior cerebellar artery.

CEREBELLUM. Anterior and posterior inferior cerebellar arteries. Superior cerebellar artery.

MIDBRAIN. Interpeduncular space—Basilar and posterior cerebral arteries.

Peduncles—Posterior communicating and basilar arteries. Remainder—Posterior cerebral artery.

Velum interpositum and chorioid plexus—Posterior cerebral artery.

BASILAR SURFACE OF BRAIN. Posterior communicating artery.

OPTIC CHIASM AND TRACT. Anterior cerebral, anterior communicating, internal carotid, posterior communicating and anterior chorioid arteries.

CORPUS STRIATUM. Anterior cerebral artery. Middle cerebral artery.

CHORIOID PLEXUS OF LATERAL VENTRICLES. Anterior and posterior chorioid arteries. Anterior chorioid artery from internal carotid artery—enters antero-inferior portion of chorioid fissure to form the most dependent portion of chorioid plexus over hippocampus. Posterior chorioid artery con-

sists often of a number of twigs from the posterior cerebral artery to the upper part of the fissure, the velum interpositum and the chorioid plexus.

CORTICAL BRANCHES. The cortex of the hemispheres is supplied by the cortical branches of the anterior, middle and posterior cerebral arteries. The middle cerebral is the largest and supplies the greater part of the convexity, the outer one-half of the orbital surface of the frontal lobe and the anterior part of the temporal lobe.

The anterior cerebral artery is the vessel supplying the anterior two-thirds of the mesial surface of the convexity and the adjoining zones along the external and orbital surfaces.

The posterior cerebral artery supplies the mesial and tentorial surfaces of the occipito-temporal region and the postero-inferior margin of the hemispheres.

The occipital lobe is supplied entirely by the posterior cerebral artery. The other lobes are supplied by more than one artery.

Frontal Lobe. Anterior cerebral artery—Mesial surface, superior frontal, anterior two-thirds of the middle frontal convolution, upper end of precentral and the orbital surface internal to the olfactory sulcus.

Middle cerebral artery—The remainder of the lobe.

Parietal Lobe. Middle cerebral artery—Entire lateral surface except a narrow strip along the upper border.

Anterior cerebral artery—Narrow strip along upper border of the lobe.

Temporal Lobe. Middle cerebral artery—Superior and upper one-half of middle temporal convolutions of the temporal lobe.

Posterior cerebral artery—Remainder of the lobe.

Limbic Lobe. Anterior cerebral artery—Gyrus cinguli to the isthmus.

Posterior cerebral artery—Remainder of lobe caudal to the isthmus.

THE VENOUS DRAINAGE OF THE SKULL AND ITS CONTENTS

General Divisions of the Venous Circulation. The return circulation of the brain and its coverings comprises a number of independent systems, which are the sinuses of the dura mater, the meningeal veins, the diploic veins and the veins of the brain itself. These systems present many intercommunications and certain differences when compared with the systemic veins. The dural sinuses are unique, there being no similar structures elsewhere in the body. The cerebral veins are more delicate in structure than the systemic veins, all the coats being reduced in strength and thickness, and they are also devoid of valves. The usual arrangement of an artery accompanied by a pair of *venæ comites* is not adhered to in the brain or its coverings, quite independent lines of drainage having been selected and developed. The main line of drainage is that provided by the confluence of the sinuses to form the internal jugular vein, and the great preponderance of the blood leaving the brain and coverings does so by means of this channel.

The Venous Pressure. The venous pressure within the sinuses is very low and it may at the end of inspiration become a negative quantity due to

the aspiratory effect of the increased thoracic capacity acting upon the almost rigid and non-collapsible walls of the sinuses. This aspiratory action of inspiration is facilitated by the absence of valves in the cerebral and cerebellar veins and would result in serious depletion of the blood supply of the brain were it not that this tendency is minimized by a number of factors:

- (a) The obliquity of the entrance of the veins into the sinuses.
- (b) The right angle turn of the superior longitudinal sinus into the lateral sinus at the torcular Herophili.
- (c) The tortuous course of the lateral and sigmoid sinuses.
- (d) The narrow exit for the blood at the jugular foramen.

The pressure of the cerebrospinal fluid, although less than the arterial pressure, is greater than the pressure within the venous sinuses, and this fact conditions the passage of the cerebrospinal fluid into the venous system after it has performed its functions.

The System of the Dural Sinuses. The sinuses of the dura mater are venous channels enclosed within the substance of the dura mater. They are formed by a splitting in certain definite localities between the two layers of the dura mater. They vary in form, being triangular, semicylindrical or cylindrical, and are composed of two coats, the outer layer of the dura externally and the inner layer internally, and a lining membrane of endothelium. The cavity of the sinuses is divided and broken up by many crossing bands of fibrous tissue called the *chordæ Willisii*. These bands, although they pass through the cavity of the sinus, are clothed with endothelium. Situated on each side of the sinuses, particularly the superior longitudinal sinus, are the dural *lacunæ sanguines* or the *parasinoidal lacunæ*, which consist of spaces between the layers of the dura mater which are in direct connection with the sinus. These often contain Pacchionian granulations. The relations of these lacunæ are as follows: (1) They communicate with the sinus along whose course they are situated either by orifices or by canals which may be one or two centimeters in length. (2) They communicate with the meningeal veins which may empty into the lacunæ. (3) They serve as drainage points for the cerebral veins, which pass from the pia mater through the arachnoid and enter the lacunæ. They are connected with the (4) diploic system of veins and (5) the emissary veins, by which communications between the interior and the exterior of the skull are rendered possible. These lacunæ act as reservoirs and safety valves for the intracranial circulation, preventing undue filling and distension of the sinuses, meningeal and cerebral veins, and providing points where excessive accumulations of blood can be diverted into extracranial channels.

As described in connection with the arachnoid, the interior of certain of the sinuses presents invaginations of the arachnoid called the *Pacchionian bodies*, which serve as filters to pass the cerebrospinal fluid on into the general circulation, thus rendering possible the circulation of the cerebrospinal fluid.

DIVISIONS OF THE SYSTEM OF THE SINUSES. The sinuses may be divided into two sets:

1. The paired sinuses.
2. The unpaired sinuses.

In general, the paired sinuses occur in connection with the base of the skull, whereas the unpaired sinuses exist along the vault and in the interior of the cranial cavity.

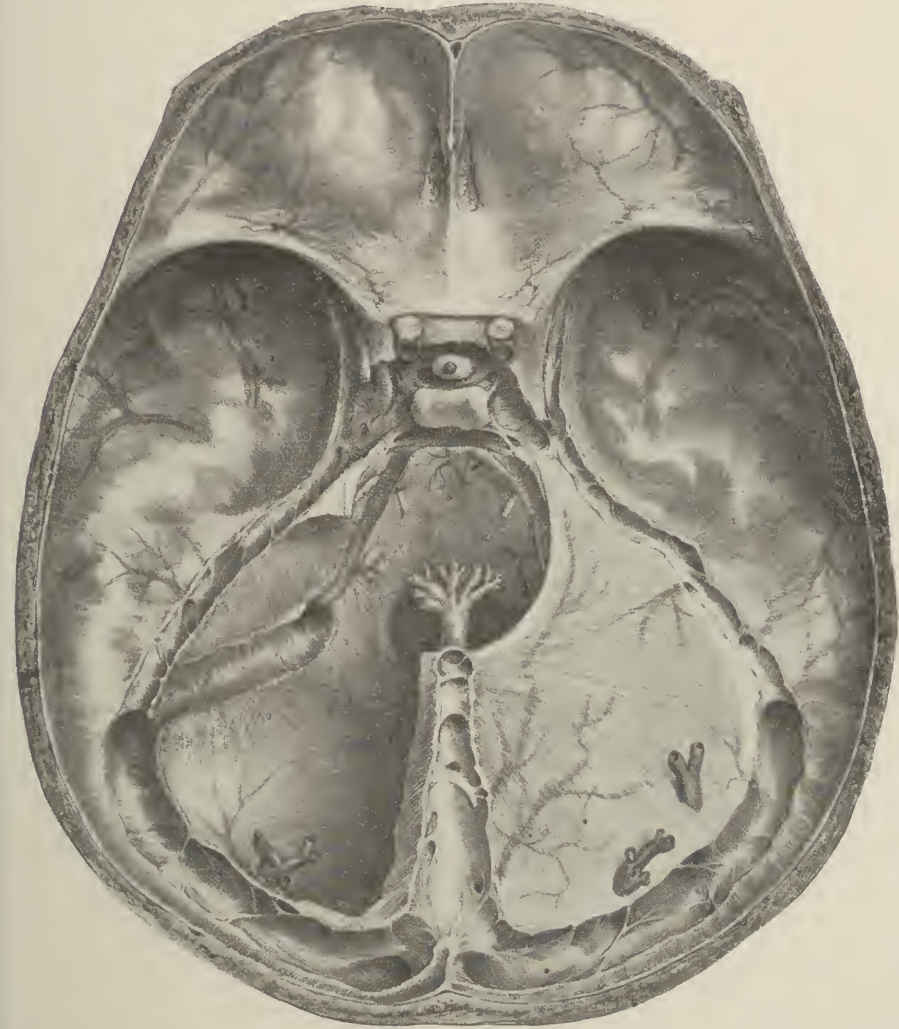


FIG. 479.—Dissection showing the sinuses which form the principal venous channels at the base of the skull. The sinuses laid open are in regular order from before backward. The circular sinus, the cavernous sinus, the transverse sinus, the superior petrosal sinus, the inferior petrosal sinus, the lateral sinus, the inferior longitudinal sinus and the straight sinus. (*Bourcery.*)

The Paired Sinuses. The paired sinuses consist of five pairs: (a) The lateral, (b) the occipital, (c) the cavernous, (d) the superior petrosal, and (e) the inferior petrosal sinus.

The Unpaired Sinuses. The unpaired sinuses are five in number and are situated in or along the midline. They consist of (a) the superior longitudinal, (b) the inferior longitudinal, (c) the straight, (d) the coronary and the transverse sinus.



FIG. 480.—Dissection showing the superior longitudinal sinus. The sinus has been laid open sagittally to expose the mouths of the inosculating cerebral veins and venous lacunæ. (*Bourguery.*)

THE DRAINAGE LINES OF THE SINUSES. The main drainage lines of the dural sinus may be distinguished as the drainage system of the vault and the drainage of the base. The drainage of the vault is performed by the superior

and inferior longitudinal and the occipital sinuses which pass into the two lateral sinuses and thence to the jugular foramen to form the internal jugular veins. The drainage of the base begins by the confluence of the ophthalmic veins to form the cavernous sinus on each side. They pass backward and then divide to form the superior and inferior petrosal sinuses which join the lateral sinus, the former at the beginning of the sigmoid sinus and the latter below the jugular foramen at the jugular bulb.

For the sake of simplicity of description, the sinuses will be considered in accordance with the drainage plan which they represent.

THE SINUSES OF THE VERTEX. *The Superior Longitudinal Sinus.* The superior longitudinal sinus is an unpaired median sinus and is located along the attached border of the falx cerebri. It extends from the *crista galli* of the ethmoid bone where it begins as a small vein from the *foramen cecum*, along the curve of the calvarium to the internal occipital protuberance, where in the great majority of cases it turns to the right to be continued as the *right lateral sinus*. Its course along the calvarium may be traced by the presence of a groove which becomes progressively wider and deeper as the internal occipital protuberance is approached, indicating the increase in size of the sinus. The groove is marked along its course by indentations in the bone indicating the presence within the sinus of the Pacchionian granulations. The superior longitudinal sinus measures in the average 1.5 millimeters at its origin and 11 millimeters at its termination. The sinus is prismatic in outline, with curvilinear sides, and with its base against the calvarium. In its course, the superior longitudinal sinus receives many affluents.

1. *Cerebral Veins.* Veins from the mesial surface and a part of the veins from the lateral surface of the cerebral hemispheres.

2. *Anterior Anastomotic Cerebral Vein of Trolard.* This vein, in the majority of cases, arises from the middle portion of the superior petrosal sinus, often from the cavernous sinus. It is directed at first outward and forward toward the lesser wings of the sphenoid, then passes into the Sylvian fissure, upward and backward over the middle third of the lateral surface of the hemispheres. It anastomoses with the inferior, middle and superior sets of cerebral veins to empty eventually into the superior longitudinal sinus in its posterior one-third.

3. *Posterior Anastomotic Cerebral Vein of Labbé.* Which arises from the lateral sinus and passes across the posterior one-third of the hemisphere to open directly into the superior longitudinal sinus or indirectly into the sinus through junction with the vein of Trolard.

4. *Middle meningeal veins, the diploic veins and the emissary vein of Santorini,* open into the superior longitudinal sinus or into the perisinal lacunæ in connection with the sinus.

5. In the fetus, the superior longitudinal sinus communicates with the veins of the nasal cavity.

The circulation of blood in the superior longitudinal sinus is from before backward. The superior cerebral veins present a peculiar arrangement as

they join the sinus; the most anterior veins open at right angles or at an obtuse angle into the sinus, but as the caudal termination of the sinus is approached, this angle becomes more and more acute, the cerebral veins finally opening into the sinus in a direction contrary to the direction of the flow within the sinus.

The superior longitudinal sinus may be double, and at the junction of the interparietal and lambdoid sutures the two channels may separate and follow the lambdoid suture to the point of origin of the sigmoid sinus.

The Inferior Longitudinal Sinus. The inferior longitudinal sinus is usually small and is located along the free concave edge of the falx cerebri. It begins at about the junction of the anterior and middle thirds of the falx cerebri and becomes progressively larger as it is traced caudally. It terminates by emptying into the *straight sinus*, which is located in the tentorium along the line of attachment between the falx cerebri and the tentorium. The inferior longitudinal sinus receives the following tributaries:

- (1) Veins from the ventral one-third to one-half of the falx cerebri.
- (2) A number of veins from the corpus callosum .
- (3) A number of veins from the gyrus cinguli.
- (4) Veins from the quadrilateral lobe and the cuneus on the mesial surface of the hemispheres.

The Straight Sinus. The straight sinus is situated in the tentorium along the line of junction between the tentorium and the falx cerebri and is formed by the confluence of the *inferior longitudinal sinus* and the *great vein of Galen* which drains a large part of the brain mass. It is prismatic in form and is directed from before backward and downward. It is the direct continuation of the inferior longitudinal sinus. It terminates at the internal occipital protuberance by turning, in the great majority of cases, to the left to form the left lateral sinus. In its course, the straight sinus receives as tributaries the following vessels:

- (1) The inferior longitudinal sinus.
- (2) The great cerebral vein of Galen which by its junction with the inferior longitudinal sinus forms the straight sinus.
- (3) The superior cerebellar veins from the dorsal surface of the cerebellum.

THE TORCULAR HEROPHILI. In tracing the superior and inferior longitudinal sinuses, they have led directly in the case of the former, indirectly in the case of the latter, through the intervention of the straight sinus to the first of the paired sinuses to be studied, the *lateral sinuses*. At the internal occipital protuberance is found a confluence of dural sinuses, the *superior longitudinal sinus*, the *straight sinus*, and the *occipital sinuses*, called the *torcular Herophili*. This structure is rarely uniform. Occasionally one reservoir may be present, which condition has been found in a more or less modified form in 20 per cent of cases. The usual arrangement is for the superior longitudinal sinus to deviate to the right and pass into the right lateral sinus. Under such circumstances the straight sinus turns to the left and becomes the left lateral sinus. The *right occipital sinus* usually passes into the right lateral sinus very close to

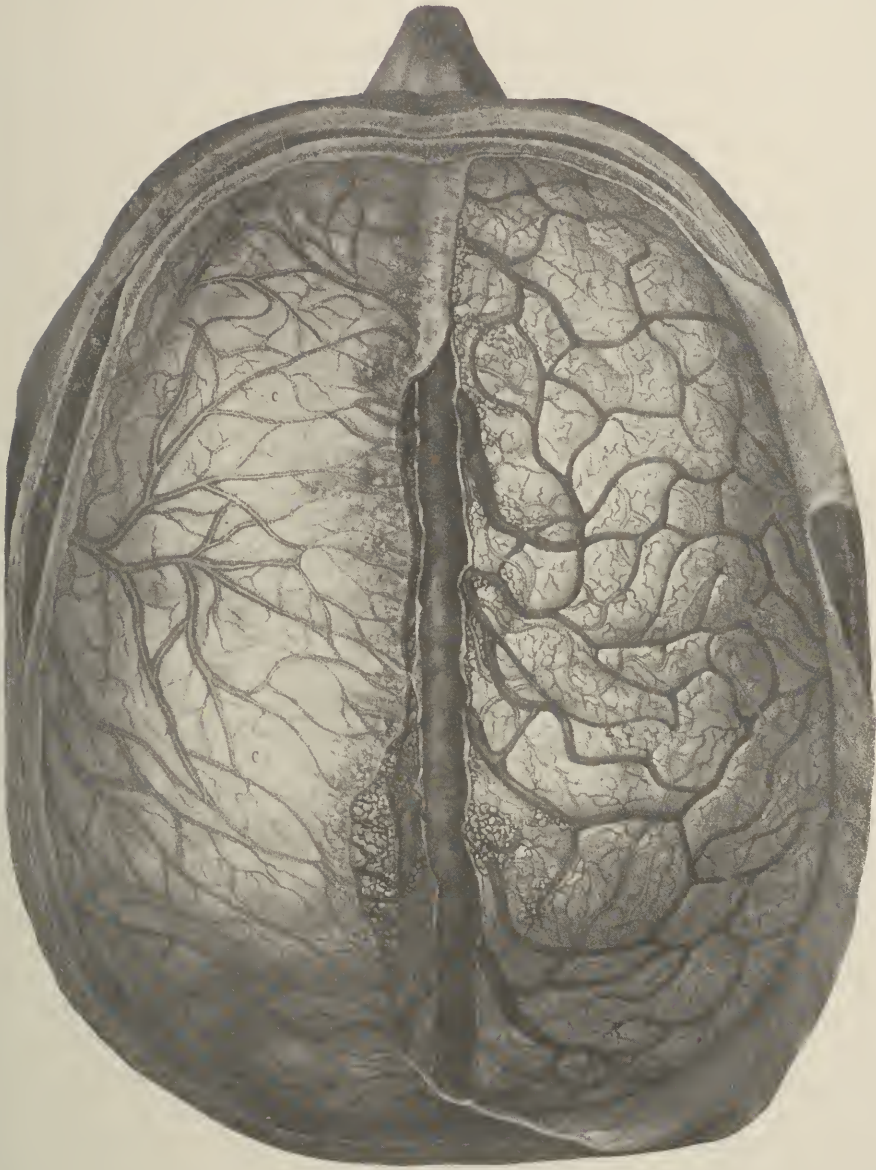


FIG. 481.—Dissection showing the chief dural arteries and principal cerebral veins. The dura has been reflected upon the right side and the superior longitudinal sinus opened. The dissection discloses the Pacchionian bodies and the cerebral veins in relation with the superior longitudinal sinus. Upon the left are the branches of the meningeal arteries in the dura mater. (*Bourger*.)

its beginning, and the *left occipital sinus* in like manner enters the left lateral sinus. This arrangement presents corresponding grooves on the internal table of the occipital bone. In the conventional arrangement a small communication is usually present between the terminations of the superior longitudinal and the straight sinus. In exceptional cases both the superior longitudinal sinus and the straight sinus may divide and form a plexus overlying the internal occipital protuberance. With the usual arrangement, the right lateral sinus drains the convexity of the brain, while the left lateral sinus contains the blood returning from the base and interior of the brain.

The Lateral Sinuses. These sinuses vary in their origin as has been shown above, but in their course they follow almost identical routes on either side of the cranial cavity. The *right lateral sinus* is generally larger than the left, usually measuring nine to twelve millimeters, while the left measures three to five millimeters at its origin. The lateral sinuses are located at the caudal and ventral portion of the cranial cavity at the point of attachment of the tentorium to the inner table of the skull. Lying between the two layers of the tentorium along its attached border, they are thus placed on the line which separates the cerebral from the cerebellar fossa. They extend from the internal occipital protuberance caudally, to the jugular or posterior lacerated foramen cephalically. Their course is rather devious, and in their various portions they receive special names. After leaving the vicinity of the torcular Herophili, the lateral sinus passes laterally around the curve of the occiput lying in a groove on the inner table of the bone. Arriving at the parieto-occipital suture at a point corresponding to the external angle of the occipital bone, it passes from the occipital to the parietal bone, still lying in a deep groove between the attached lips of the tentorium. Having traversed the posterior inferior angle of the parietal bone, the sinus reaches the petrosa. At this point it changes its course and leaves the tentorium. The tentorium passes inward and forward along the superior border of the petrosa. The sinus turns downward forming the *genu* of the lateral sinus in a groove on the inner surface of the temporal bone, called the *petro-mastoid groove*, and becomes the *sigmoid sinus*. The genu of the lateral sinus extends further forward on the right side than on the left. At this point the lateral sinus may receive a small sinus called the *petro-squamosal sinus* which lies along the petro-squamosal suture. It then crosses the inner surface of the mastoid portion of the temporal bone, passing downward and somewhat backward. Reaching the masto-occipital suture, the sinus again becomes more horizontal, and crossing the suture, lies upon the jugular process of the occipital bone. Meeting the jugular or posterior lacerated foramen, the sinus enters the most lateral of the three compartments in the foramen and emerges from the base of the skull. It may pass through a *foramen jugulare spurium*, and then enter the jugular bulb. At the base of the skull the sinus dilates, receives the inferior petrosal sinus and thus becomes the bulb of the internal jugular vein. The upper surface of the jugular bulb forms a dome-shaped structure which projects upward into the opening of the jugular foramen on the inferior surface of the base of the skull. By certain authors,

that portion of the sinus between the point where it leaves the tentorium and the point where it turns downward as the sigmoid sinus, is called the *transverse sinus*, the exact point of transition being marked externally by the junction of a vertical line through the tip of the mastoid process and a horizontal line through the zygomatic process. By other authors, the terms lateral and transverse sinus are interchangeable.

Along its course the sinus receives the following tributaries:

- (1) The posterior cerebellar veins.
- (2) The inferior cerebral veins, from the temporo-sphenoidal region.
- (3) The posterior cerebral veins.
- (4) At the beginning of the sigmoid sinus, the sinus receives the termination of the superior petrosal sinus.
- (5) Within the jugular foramen, the sinus receives the posterior condyloid vein which emerges from the posterior condyloid foramen.
- (6) At the bulb of the internal jugular vein the sinus receives the inferior petrosal sinus.
- (7) Internal auditory veins.

The lateral sinus usually receives two emissary veins which connect it with the extracranial circulation. At or very near to the masto-occipital suture, is located the mastoid foramen, which may be of great size and transmits the *mastoid emissary* vein. The lateral sinus has been seen to pass bodily through the mastoid foramen and empty into the posterior auricular vein, in which case the sigmoid sinus was continued as only a very small channel. The second emissary vein of the lateral sinus is usually located at the posterior lacerated foramen, where a vein leaves the lateral part of the sinus and passing through a foramen in the squamosa, emerges on the exterior of the skull and joins the deep temporal vein.

The Occipital Sinuses. Near the origin of each lateral sinus at the internal occipital protuberance, the *occipital sinus* enters the corresponding lateral sinus on each side. The occipital sinuses arise along the cephalic limb of the foramen magnum in a plexus of veins which is continuous ventrally with the termination of the lateral sinus in the bulb of the internal jugular vein and with the most cephalic of the spinal veins. The sinuses form in the dura mater lining the circumference of the foramen magnum. Gradually increasing in size, they pass around the circumference of the foramen magnum and then upward on either side of the inferior limb of the *internal occipital cruciform crest*, emptying into the lateral sinuses close to their points of origin at the internal occipital protuberance. The two sinuses may join and lie in the attachment of the falx cerebelli and open into either of the lateral sinuses. The occipital sinuses are also called the *marginal sinuses*.

The occipital sinuses receive:

- (1) Dural branches.
- (2) Diploic branches.
- (3) A few of the inferior cerebellar veins.

Uniting at either extremity with the beginning and the end of the lateral sinus, the occipital sinuses act to equalize the pressure within the lateral sinus.

THE SINUSES OF THE BASE. The second line of drainage follows the base of the skull and originates by the confluence of the ophthalmic veins to form the cavernous sinus.

The Ophthalmic Veins. The ophthalmic veins drain the contents of the orbit and produce two trunks, a large superior trunk and a small inferior trunk.

The *superior ophthalmic vein* arises at the inner angle of the orbit by the fusion of two vessels, the supra-orbital and the angular veins. It passes below the pulley for the superior oblique muscle, and following a tortuous course backward and outward across the optic nerve and beneath the superior rectus muscle, it then passes directly backward to the *sphenoidal fissure* where it meets the inferior ophthalmic vein.

The *inferior ophthalmic vein* originates from a network of veins in the inner portion of the floor of the orbit. It communicates with the facial vein. Out of this network of veins emerges one larger trunk which unites with the superior ophthalmic vein in the sphenoidal fissure to form the cavernous sinus. The *ophthalmic veins* are true cerebral veins in that they contain no valves. They establish a voluminous communication between the dural sinuses and the superficial system of veins by means of junctions with the facial veins, the veins of the nasal cavity through the ethmoidal veins and with the pterygoid plexus of veins by way of the vessels which pass through the sphenomaxillary fissure and end in the pterygoid plexus of veins.

The Cavernous Sinus. The cavernous sinus is remarkable for its relatively great size and the shortness of its course. Situated, one on each side of the *sella turcica*, they are contained within the reduplications of the dura which form the lateral walls of the osseo-membranous pituitary fossa. They are directed cephalo-caudally and extend from the sphenoidal fissure to the summit of the petrosa, where they terminate by dividing into the *superior* and *inferior petrosal sinuses*. They are crossed by many interlacing bands of fibrous tissue which divide the sinus into a number of anastomosing channels. The sinus near its termination is invaded by the *internal carotid artery*, which upon emerging from the carotid canal, finds the cavernous sinus placed directly above its exit from the canal. The artery enters the sinus, running first forward and upward, and then turning directly upward pierces the roof of the sinus to emerge into the cranial cavity. The *abducens nerve* also enters the cavity of the sinus passing from behind forward and from above downward toward the sphenoidal fissure. These two structures although they lie within the cavity of the sinus, nevertheless are covered by a layer of endothelium.

In the outer wall of the cavernous sinus are situated the *ophthalmic division* of the *trigeminal nerve*, the *trochlear nerve* and the *oculomotor nerve*, passing forward on their way to the sphenoidal fissure by means of which they enter the orbital cavity. The ophthalmic division of the trigeminal nerve enters the ventral portion of the outer wall of the sinus as the sinus passes over the mesial portion of the Gasserian ganglion, and is the most ventral of the three nerves in position in the lateral wall of the sinus. The

trochlear nerve enters the lateral wall of the sinus at the point where it pierces the triangular reflection of the dura which fills in the space between the two extremities of the tentorium. It lies above the ophthalmic division of the trigeminal nerve and below the oculomotor nerve. The trochlear nerve follows a slightly oblique course through the wall of the sinus, and upon arriving at the sphenoidal fissure is slightly dorsal to the oculomotor nerve. The oculomotor nerve enters the lateral wall of the cavernous sinus in a manner similar to that followed by the trochlear nerve, but is placed more dorsally and passes close by and ventral to the posterior clinoid process. Its direction in the sinus wall is slightly ventral, so that in its course forward it passes mesial to the trochlear nerve appearing at a slightly lower level than this nerve at the sphenoidal fissure.

The cavernous sinus in its course receives a number of tributary veins:

(1) The superior ophthalmic vein.

(2) The inferior ophthalmic vein.

(3) The anterior cerebral veins which drain the caudal part of the orbital surface of the frontal lobe. Those veins enter the superior aspect of the sinus.

(4) The inferior cerebral veins. One of these inferior cerebral veins is usually a large vessel and runs in the horizontal limb and stem of the Sylvian fissure. It is called the *superficial Sylvian vein* and establishes connection with the great anastomotic vein of Trolard.

The Speno-Parietal Sinus. Occasionally one of the inferior cerebral veins may assume the characteristics of a sinus running along the edge of the lesser wing of the sphenoid bone. In such cases it is known as the *spheno-parietal sinus*. The spheno-parietal sinus, or the *sinus alæ parvæ*, begins as a meningeal vein in the dura mater covering the lesser wing of the sphenoid. Increasing in size it passes mesially to empty into the cavernous sinus. It receives as tributaries:

(1) Dural vessels.

(2) Diploic vessels.

(3) A number of anterior cerebral veins.

The communications of the cavernous sinus are as follows:

(1) Laterally with the middle meningeal veins.

(2) With the pterygoid plexus of veins by means of a vein which passes laterally and enters the foramen ovale or the foramen Vesalii, and emerging from the base of the skull enters the pterygoid plexus of veins.

(3) With the internal jugular vein through a number of fine vessels which accompany the internal carotid artery through the carotid canal and thus reach the internal jugular vein.

(4) With the angular vein through the superior ophthalmic vein.

The Coronary Sinus. This sinus, sometimes called the *circular sinus*, consists of a double cross anastomosis between the two cavernous sinuses, the two vessels being given off from the dorsal portion of the mesial walls of the cavernous sinus. They lie in the diaphragma sellæ cephalad and caudad to the infundibulum of the pituitary gland, and form a horizontal ellipse with its axis transverse. The cephalic limb is limited cephalically by

the attachment of the diaphragma sellæ to the caudal lip of the optic groove in which is lodged the optic chiasm. Caudally the caudal limb is limited by the attachment of the diaphragma sellæ to the dorsum sellæ. They serve to equalize the intrasinal venous pressure. The sinus has as tributaries to it veins which emerge from the pituitary gland.

The Transverse Sinus. At the caudal end of the cavernous sinuses, serving as an intercommunication between them, is the *transverse occipital* or basilar sinus. It is situated between the two layers of dura covering the basi-sphenoid bone and unites the ventro-caudal terminations of the cavernous sinuses.

At the tip of the petrosa, the cavernous sinuses terminate by dividing into the *superior* and *inferior petrosal sinuses*.

The *superior petrosal sinus* is small and passes off from the dorso-lateral extremity of the cavernous sinus. Lying along the superior border of the petrous portion of the temporal bone, it is contained within the line of attachment of the tentorium. It occupies a groove in the superior border of the petrosa. It terminates by emptying into the lateral sinus as the latter leaves the attachment of the tentorium on the inner surface of the petroso-mastoid portion of the temporal bone, and turns downward and inward as the sigmoid sinus.

The superior petrosal sinus receives the following tributaries:

- (1) Certain of the anterior cerebral veins.
- (2) A number of superior cerebellar veins.
- (3) Veins from the tympanic plexus of veins.
- (4) A number of diploic veins.

The *inferior petrosal sinus* is the direct continuation of the cavernous sinus and is more voluminous than the superior petrosal sinus. It is directed obliquely downward and outward and follows the petro-occipital suture lying in a groove along its internal surface. Reaching the cephalic extremity of the jugular or posterior lacerated foramen, the inferior petrosal sinus turns downward at almost a right angle and entering the cephalic or mesial compartment in the foramen, passes through the foramen and arrives on the external surface of the base of the skull. At this point it loses its sinus characteristics, and acquiring those of a true vein, it opens into the bulb of the jugular vein which lies directly below the foramen.

In its course the inferior petrosal sinus receives the following tributaries:

- (1) Inferior cerebellar veins.
- (2) Auditory veins from the internal ear.
- (3) A group of veins from the anterior condyloid foramen which arises from a number of sources:
 - (a) Vertebral veins.
 - (b) Spinal veins.
 - (c) Extravertebral veins.

The Communications between the Extra- and Intra-Cerebral Circulation. THE EMISSARY VEINS. The emissary veins connect the intra- and extra-cerebral circulation. The sinuses of the dura mater are connected at

certain points with the superficial integumentary and the deep systems of systemic veins. These communications serve as safety valves by which differences in pressure within and without the skull may be equalized. In these veins, the direction of the current is reversible, the passage of blood being possible in either direction. The emissary veins found along the course of the various sinuses are as follows:

The Emissary Veins of the Superior Longitudinal Sinus. The *emissary veins of Santorini*. These veins pass through the parietal foramen and unite the superior longitudinal sinus with the parietal veins.

The Emissary Veins of the Lateral Sinus. (1) The *occipital emissary vein*, which leaves the torcular Herophili or the lateral sinus and passes backward through the occipital bone to join the occipital veins. This vein may fail to pierce the external table and may establish connection only with the diploic system of veins.

(2) The *mastoid emissary vein*, which passes through the mastoid foramen to unite the lateral sinus and the mastoid and posterior auricular veins.

(3) The *posterior condyloid vein*, which leaves the lateral sinus at its termination and passes through the posterior condyloid foramen to enter the vertebral plexus of veins between the axis and the atlas.

The Emissary Veins of the Cavernous Sinus. (1) A vein which passes through the foramen ovale to end in the deep pterygoid plexus of veins.

(2) A vein through the foramen lacerum medium to the same plexus.

(3) A vein through the foramen of Vesalius to the same plexus.

(4) A vein through the foramen rotundum to the same plexus.

(5) A number of veins which accompany the internal carotid artery and empty into the internal jugular vein.

(6) The *inferior petro-occipital sinus*, which passes through the posterior lacerated foramen and joins a group of veins which lie in the anterior condyloid fossa.

The Emissary Vein of the Inferior Petrosal Sinus. The *anterior condyloid vein* passes through the anterior condyloid foramen in company with the hypoglossal nerve and joins the vertebral veins.

SUPPLEMENTARY COMMUNICATIONS. In addition to the communication afforded between the extracranial and intracranial circulations by means of the emissary veins, the two circulations are rendered supplementary by the communications between the *dural sinuses* and the *meningeal* and *diploic systems* of veins. The two circulations also become confluent through connections with vessels which either give origin to the dural sinuses or receive them; such as the inconstant connection between the superior longitudinal sinus and the nasal veins through the vein in a patent foramen cecum; the origin of the cavernous sinus from the ophthalmic veins which communicate with the facial venous system; the origin of the occipital sinus from the vertebral veins; the termination of the lateral sinus and inferior petrosal sinus directly, and the superior petrosal sinus indirectly in the internal jugular vein.

Practical Considerations in Regard to the Dural Sinuses.

INFECTION may reach the dural sinuses through a number of points of entrance.

- (1) From the scalp through the agency of the diploic veins.
- (2) From cerebral or meningeal disease either through the lacunæ or the cerebral or meningeal veins.
- (3) From the nose through the vein in the foramen cecum in children.
- (4) Through compound fractures of the skull producing depressions and infection of the bones of the skull and direct extension to the sinuses.

THROMBOSIS of the dural sinuses may result from: (1) Compression or infection following depressed fractures or disease of the bones of the skull.

- (2) Marasmic conditions in infants.

The rigidity, width, trabeculation and the entrance of the veins into the sinus all tend to retard the rate of the blood current in the dural sinuses.

NEVI may be found in the skin which arise or communicate with the dural sinuses through natural orifices or developmental defects in the bones of the skull. Occasionally blood lakes may be found beneath the skin which communicate with the sinus and which pulsate synchronously with the pulsation of the heart.

The cavernous sinus is particularly open to infections which may arise in the orbit and extend backward through the ophthalmic veins. Similarly, infections arising in the face, mouth, alveolo-dental region, nasal antrum and the frontal sinus, osteomyelitis of the frontal bone, etc., may spread to the cavernous sinus. Exophthalmos, edema, chemosis and symptoms referable to the ophthalmic division of the trigeminal nerve, to the third, fourth and sixth cranial nerves, all indicate a lesion involving the cavernous sinus.

On account of the unique relationship between the cavernous sinus and the internal carotid artery, a fracture of the base running through the pituitary fossa may be followed by an arterio-venous aneurysm between the internal carotid artery and the cavernous sinus. In this case there will be present a pulsating unilateral exophthalmos with paralysis and anesthesia as a result of pressure on the nerves contained within the walls of the cavernous sinus.

The Diploic System of Veins. This system of veins exists in the cancellous tissue between the two tables of the skull and consists of a system of lacunæ or spaces which are very variable in form and dimensions. They freely communicate with one another. Among these irregular spaces, certain lines of drainage develop which are inconstant and irregular. Each cranial bone seems to have a more or less distinct system enclosed within the confines of that bone. Intercommunications between the diploic systems of individual bones seem to be established only in advanced years. The caliber of the diploic veins varies greatly according to the age of the individual. They are not present in infants and increase with age, being quite voluminous in the aged. The form of the individual channels is variable, but in general they are rectilinear and present a bony wall covered by a layer of endothelium.

There are four main collecting channels for the diploic venous plexus, one in the frontal bone, two in the temporal bone—one cephalically, the other caudally—and one in the occipital bone. These collecting channels are directed from above downward.

(1) The *frontal diploic vein* drains the anterior portion of the frontal bone and empties into the supra-orbital vein by traversing a small foramen in the external table in the supra-orbital notch.

(2) The *anterior temporal diploic vein* collects the return circulation from the posterior part of the frontal bone, the anterior portion of the parietal

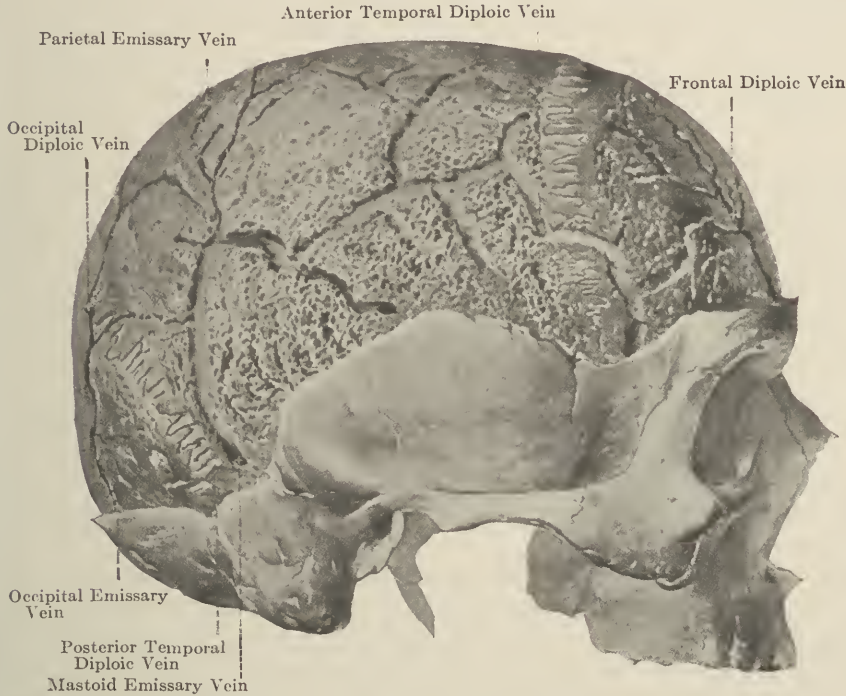


FIG. 482.—Diploic veins, viewed from the right; the lamina externa of the roof of the skull has been filed off. (*Spalteholz.*)

and temporal bones, and empties into the spheno-parietal sinus or the anterior deep temporal vein.

(3) The *posterior temporal diploic vein* drains the posterior part of the parietal and temporal bones and terminates in the lateral sinus by piercing the inner table of the skull.

(4) The *occipital diploic vein*, usually of considerable size, drains the occipital bone and terminates either externally in the occipital vein or internally in the lateral sinus.

The diploic veins serve further to increase the number of communications between the extra-cranial and the intra-cranial circulation. In addition to the points of drainage, the diploic veins have many points of communication with the sinuses and with the extra-cranial veins through internal

and external orifices. The internal orifices are located by preference in the vicinity of the vascular grooves which mark the internal tables of the skull. They also communicate with the meningeal system of veins. They frequently open into the lacunæ and the spaces in which lie the Pacchionian granulations. The external orifices traverse the external tables and the veins pierce the epicranium and enter the venous plexus of the scalp. These vessels may be seen particularly in the frontal and occipital regions.

PRACTICAL CONSIDERATIONS OF THE DIPLOIC SYSTEM OF VEINS. The diploic veins, being incapable of contraction since their endothelial lining is based directly upon cancellous bony tissue, bleed freely if opened.

Through their extra- and intra-cranial connections they frequently are the cause of infections spreading to the interior of the skull. Compound fractures of the skull and osteomyelitic necrosis of the cranial bones may thus result in meningitis or septic thrombosis and a terminal pyemia. Infections spread rapidly in the diploic tissue.

The Venous System of the Cranial Integument. Between the scalp and the aponeurosis there exists a very rich venous plexus. This plexus is irregular and presents no basis for a systematic description. The general plexus can be divided according to its location into three groups, an anterior or frontal, a posterior or occipital and a lateral or temporal group. These systems have a very rich anastomosis and descending vertically terminate as follows:

- (a) The frontal group is collected together and joins the facial veins.
- (b) The occipital group forms one or two main trunks which are collected together and eventually reach the external jugular vein.
- (c) The temporal group converges toward the zygoma and empties into the superficial temporal vein.

The Veins of the Cerebrum and Cerebellum. **GENERAL CHARACTERISTICS.** Unlike the systemic veins, the cerebral veins do not accompany the corresponding arteries but develop independent areas and lines of drainage. The cerebral veins are relatively thin-walled and are devoid of valves. They contain little, if any, muscle tissue in their walls. They ramify between the layers of the pia mater.

THE VEINS OF THE CEREBRUM. *The Superior Cerebral Veins.* These veins vary from eight to twelve in number, and drain the upper, lateral and mesial surfaces of the hemispheres. They tend to follow the sulci, are connected across the gyri by anastomosing trunks and open into the superior longitudinal sinus by leaving the pia, traversing the arachnoid and piercing the dural covering of the sinus. They increase in size from before backward as well as opening more and more obliquely into the sinus, the cephalic veins opening at right angles, while the caudal veins open quite obliquely, from behind forward, into the sinus.

The *middle cerebral veins* drain the middle portion of the lateral surface of the hemisphere and unite to form the *superficial Sylvian vein* which lies in the Sylvian fissure and empties into either the cavernous or the sphenoparietal sinus. It receives affluents from either side of the fissure.

The middle cerebral veins communicate with both the superior and inferior cerebral veins by means of the great anastomotic vein of Trolard which lies in the Rolandic fissure and establishes communication between the great longitudinal and the cavernous sinuses.

The *inferior cerebral veins* are small and irregular in arrangement. They drain the inferior surface of the hemispheres. The frontal set open into the anterior part of the great longitudinal sinus. In the temporal region they empty into the sphenoparietal and the superior petrosal sinuses and mesially into the basilar vein.

The Veins of Galen. The interior of the brain is drained in large part by the *great vein of Galen*. In the velum interpositum, in the roof of the third ventricle near its apex on either side, is found the *small vein of Galen*. This is formed by the confluence of three veins: (1) The anterior chorioid vein, which receives the return circulation from the anterior portion of the chorioid gland of the lateral and third ventricles; (2) the vein of the septum pellucidum, and (3) the vein of the corpus striatum. The *chorioid vein* begins at the junction of the body and temporal horns of the lateral ventricle and passing forward along the floor of the ventricle at the outer edge of the chorioid plexus it arrives at the foramen of Monro. The *vein of the septum pellucidum* passes backward along the outer surface of the septum pellucidum and receives the blood from the head of the caudate nucleus and the structures in that neighborhood. The *vein of the corpus striatum* collects the venous blood from the lenticular and caudate nuclei and lies in the chorioidal sulcus between the caudate nucleus and the thalamus. These veins converging at the apex of the velum interpositum on each side join and form the *small veins of Galen*. The small veins of Galen then pass caudally on either side of the velum interpositum to its base, where they receive the *posterior vein* of the *corpus callosum*. This vein arises at about the middle of the superior surface of the corpus callosum, and passing backward turns around the splenium of the corpus callosum and joins the small veins of Galen. In their course they receive tributaries from the corpus callosum and from the inferior portions of the mesial surfaces of the cerebral hemispheres.

At the base of the velum interpositum the *small veins of Galen* join to form a single trunk, the *great vein of Galen*, which passes backward and ends by joining the straight sinus. Small veins from the thalamus enter either the great vein of Galen or the straight sinus.

The Basilar Vein. The mesial portion of the base of the brain is drained by two veins, one on each side, called the *basilar veins*. The basilar vein begins at the anterior perforated space by the junction of the *deep Sylvian vein* and the *anterior vein of the corpus callosum*. The deep Sylvian vein lies embedded in the depths of the Sylvian fissure. It begins in the insular region receiving branches from the opercula and from the island of Reil. Passing mesially and freely anastomosing with the superficial Sylvian vein, it reaches the origin of the stem of the Sylvian fissure, and uniting with the anterior vein of the corpus callosum forms the basilar vein. The anterior vein of the corpus callosum arises on the anterior part of the dorsal surface of the corpus

callosum by branches from the mesial surface of the hemispheres. It curves about the rostrum of the corpus callosum and unites at the anterior perforated space with the deep Sylvian vein.

The basilar vein passes backward over the optic tract, and curving upward around the crus cerebri enters the great fissure of Bichat. Emerging on the dorsal surface of the brain-stem it empties into the *great vein of Galen*. The basilar vein may stop short and pass into the cavernous sinus. Occasionally it may unite with the middle cerebral vein or the sphenoparietal sinus. The basilar vein drains the entire central portion of the base of the brain, the olfactory trigone, the optic tract, the anterior perforated space, the tuber cinereum, the corpora mammillaria, the posterior perforated space, the uncinate gyrus, the temporal horn of the lateral ventricle and the crus cerebri. The veins from the nuclei of the corpus striatum and the anterior limb of the internal capsule, some ten to fifteen in number, emerge from the anterior perforated space and join the basilar vein. The veins from the optic thalami and the posterior limb of the internal capsule emerge from the posterior perforated space and also join the basilar vein.

The basilar vein before terminating in the great vein of Galen may receive a number of branches which come from the superior vermis of the cerebellum.

THE VEINS OF THE CEREBELLUM. The *cerebellar veins* form an intricate network which is arranged largely at right angles to the direction of the folia. They may be divided into two sets, superior and inferior.

The *superior cerebellar veins* drain the tentorial and cephalic portion of the *petroso-ventricular surfaces* of the *hemispheres* and the *superior vermis of the cerebellum*. They terminate by entering either the lateral sinus or the *superior petrosal sinus*. Mesially they form either one trunk or several trunks which pass forward along the superior vermis and open into the *great vein of Galen* or into the terminal portion of the *basilar vein*.

The *inferior cerebellar veins* are larger than the superior and arise on the occipital and caudal portion of the *petroso-ventricular surface* of the hemispheres and the *inferior vermis* of the cerebellum. They have an arrangement similar to that of the superior cerebellar veins—a median or vermal vein which passes backward and enters the lateral sinus or the straight sinus. The lateral veins open into either the occipital or the inferior petrosal sinus.

CHAPTER XLI

THE ENDBRAIN

THE CORTEX OF THE CEREBRAL HEMISPHERES

Cortical Stratification. The endbrain of all vertebrates, with the exception of fish, presents a cortex in which there is a definite stratified arrangement of nerve cells and fibers. The complexity of this stratification varies in the different orders according to the psychic development of the animal. In amphibia and reptiles the cortex has been called into existence in response to the demand for expansion in the olfactory sphere. In birds, olfactory acuity becomes subsidiary to visual function. In mammals, the cortex attains its highest development. In these animals the pallium does not serve the purposes of a single sense alone. It is an expansion of the nervous tissue in the interests of greater correlation in all qualities of general and special sensibility.

The stratified appearance of the cerebral cortex in man was first recognized by Gennari in the calcarine area nearly one hundred and fifty years ago. This observer identified a broad, glistening stratum extending at a considerable depth beneath the surface in certain parts of the occipital lobe. This he called "*lineola albidior abmodum eleganter*" (1776), a stratum now known as the line of Gennari.

Subsequent investigations have brought to light many minute details of the cerebral cortex in man, so that its general characters are now well recognized.

The discoveries by Nissl and Golgi of special methods for cell staining furnished more exact means by which the different cellular strata of the cortex may be successfully investigated. Weigert's myelin sheath stain afforded a method for disclosing the fiber character of the pallium. These procedures have been used to great effect by a number of investigators, including Ramon y Cajal, Kaes, Hammarberg, Flechsig, Passof, Edinger and Vogt. The most recent and complete histological studies of the cerebral cortex were made by Campbell, of England, whose work serves as the most reliable guide to cerebral localization.

In general, the cerebral cortex consists of the usual elements found in the central nervous system, the white matter which constitutes the greater part of the endbrain, and the gray matter which forms the outer layer of the pallium. In lower mammals, such as the guinea-pig and rabbit, the cortex is smooth (lissencephalic cortex), while in the more highly developed mammalian brain, such as carnivores, apes and man, there is a marked degree of irregularity in the surface due to the formation of convolutions which are separated by fissures (gyrencephalic cortex).

Strata of the Cerebral Cortex in Man. In the human cortex it is possible by histological methods to distinguish seven cellular layers, and four more or less well defined fiber layers.

The cellular strata of the cortex are:

1. The plexiform layer, a layer in which there are few cells and which, because of its lack of cellular elements, has been called by Meynert, the molecular zone.

2. The layer of small pyramidal cells.

3. The layer of medium-sized pyramidal cells.

4. The layer of large external pyramidal cells.

5. The layer of stellate cells.

6. The layer of large internal pyramidal cells, or giant cells.

7. The layer of spindle-shaped and fusiform cells.

The fiber layers of the cortex are:

1. The zonal layer.

2. The supraradiary layer.

3. The layer of Baillarger.

4. The radiary layer.

Each of the several layers of cells and nerve fibers requires separate description, and must also be considered in its respective relations to other layers.

THE CELLULAR STRATA OF THE CEREBRAL CORTEX

The Plexiform Layer. In this stratum, which contains few cells as compared with other cellular layers of the cortex, several different elements are recognized, as follows:

Small and medium sized cells with short axones.

Larger cells occupying horizontal positions whose axones are tangential to and parallel with the surface of the convolution.

Terminal dendritic clusters, dendrites of pyramidal cells and of cells of the subjacent layers.

The arborizations of ascending axones.

Neuroglial cells.

The cells with the short axones in the plexiform layer are triangular, polygonal or ovoid in shape. They give off a great number of dendrites, upon the branches of which are numerous varicosities. The axone usually has a direction parallel to the surface of the cortex, and after extending for a variable distance ends in a free arborization limited to this first layer. In man the cells with short axones are subject to great variations in size and shape. They may be of medium size, triangular in shape, very large polygonal elements, much reduced pyriform, and ovoid, or they may even resemble in most details the neuroglial cells of the cortex.

The horizontal cells of the plexiform layer vary in form but are for the most part bipolar, stellate or triangular elements. The dendrites are extremely rich although short. The axones are difficult to identify on account of this dendritic richness. The axis cylinder is directed horizontally imme-

diately beneath the surface of the cortex and forms one of the groups of tangential fibers in the plexiform layer.

Other elements entering into the plexiform layer are the terminal clusters, which consist of the rich dendritic processes of pyramidal cells in the immediately subjacent layer. In addition to the dendritic processes in the plexiform layer there are some ascending axones from cells in the deeper layers. These are known as the *ascending axones of Martinotti*.

The plexiform layer also contains a number of neuroglial cells of the type present in the general cerebral cortex.

In summary, the plexiform layer consists of:

1. Cells with short and long axones, horizontally and tangentially disposed.

2. The horizontal cells of Cajal, whose axones are likewise tangential.

The dendrites of both these types of cells branch and remain in the plexiform layer.

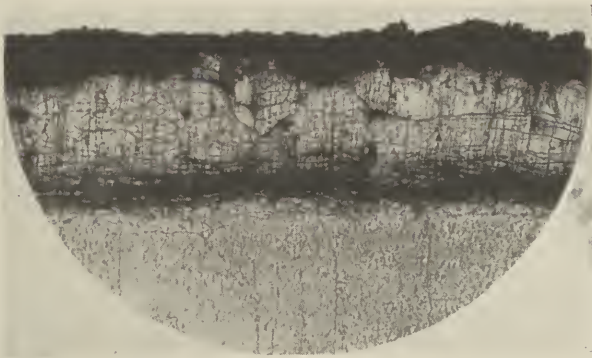


FIG. 483.—The superficial layer of the cerebral cortex of a human embryo showing Cajal cells, tangential fibers and fine interlacing vertical fibers. (Starr.)

3. The dendritic arborizations of cells in the deeper layers.

4. The ascending fibers of Martinotti.

5. The neuroglial cells.

The horizontal cells are supposed to receive impulses from the afferent nerve fibers from the cortex either directly or indirectly through the short axone cells of the Golgi type II. These impulses are then passed to the dendritic processes of the pyramidal cells which ramify in this layer. The ascending axones of Martinotti bring the plexiform layer into relation with the deeper strata of the cortex.

The Layer of Small Pyramidal Cells. This layer, like the plexiform stratum, represents about one-tenth of the depth of the cortex. It has been called the stratum of superficial polymorphous cells and constitutes a well delimited zone recognizable on account of the smallness and general constancy in size of its cellular elements. Four varieties of cells are found in this stratum:

1. Small pyramidal cells.

2. Large cells with short axones.
3. Small cells with short axones.
4. Cells of Martinotti whose axones terminate in the plexiform layer.

The *small pyramidal cells* are triangular or pyramidal in shape and give rise, usually from their base, to an axone which is directed toward the medullary substance. Their cytoplasm contains many chromophilic granules and a large ovoid nucleus with several nucleoli. The dendrites are numerous and voluminous, usually three or more in number. They terminate in the second layer. The axones of the small pyramidal cells take origin either from the body or from one of the large basal dendrites. They descend



FIG. 484.—The second layer of the cerebral cortex, the layer of small pyramidal cells, showing the bifurcation of the apical process in the superficial layer. (Starr.)

into the subjacent layers and enter the radial fasciculi. During their course in the second and third layers the axones give off three, four or even more collaterals, which are extremely fine and end about the dendrites of these strata.

The *large cells with short axones* are pyramidal in shape, although some of them are polygonal, ovoid or stellate in form. Their dendrites diverge in various directions, while their axones extend into the plexiform layer. There are also some cells of smaller size with short axones which resemble the neuroglia in their general appearance. They have a small amount of cytoplasm and a large number of radiating dendrites. The axone is fine and gives rise to a dense arborization usually confined to the layer immediately subjacent to the cell itself.

The *small cells with short axis cylinders and dense arborization of their dendrites* are ovoid, stellate or pyriform. Their axones ascend and reach the

superficial portion of the second layer. Here they break up into a rich end arborization. All of the arborizations thus formed in the first two layers constitute a dense plexus. There are also some fusiform or arachniform cells with double brush dendrites. These cells are perpendicularly oriented with reference to the surface of the convolutions. Their axones are extremely fine in calibre and leave the cell either from its body or from one of the dendrites. They descend to form a fasciculus of very delicate longitudinal filaments.

The *cells of Martinotti* give rise to ascending axones in contradistinction to the great majority of the pyramidal elements of this stratum. These

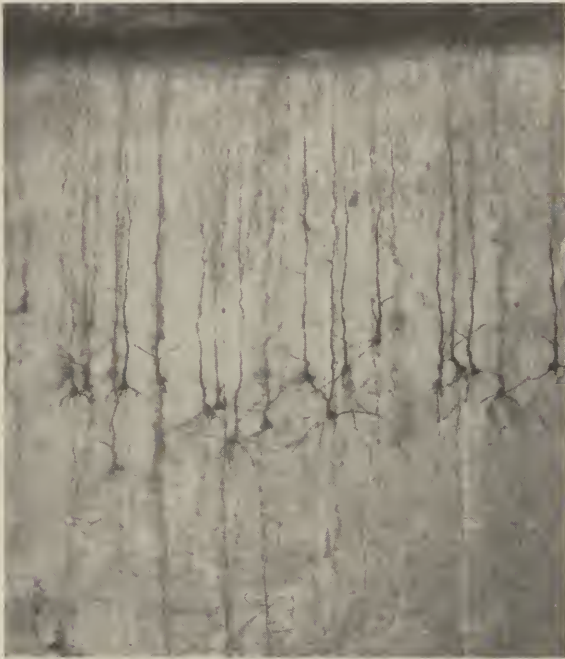


FIG. 485.—Pyramidal cells of the cerebral cortex, eight months human embryo, showing the long apical process, the numerous short basal processes and the axone with its collaterals. (*Starr.*)

axones extend to the plexiform layer and there terminate in horizontal branches of varying length. Certain peculiarities characterize these cells. They are not typical pyramidal cells, but are more globular, fusiform or ovoid in outline. They are abundant in all layers of the cerebral cortex but in the lower layers they attain their greatest dimensions and present less variety in form.

Layers of the Medium-Sized and Large External Pyramidal Cells. These two strata blend with the adjacent layers without a sharp line of demarcation. They contain several varieties of cells, the most prominent of which are the medium-sized and large pyramidal cells. The large cells vary in their diameters from 35 by 17, to 28 by 22 micra. The medium-sized

cells average 16 by 12 micra in their diameters. These pyramidal elements in all probability give rise to long pathways which leave the cerebral cortex. They therefore require a detailed description. In form they are pyramidal and contain a large ovoid nucleus with several nucleoli of large size. They have a considerable amount of cytoplasm containing Nissl bodies, while



FIG. 486.—Medium-sized pyramidal cells of the third layer of the cortex showing the long apical process entering the superficial layer and the fine axone emerging from the base of the cell. (Starr.)

their basal dendrites also contain tigroid bodies of considerable size. The neurofibrils in these cells are convergent from the dendrites to the axones which leave the cells near their base. Within the cytoplasm of the soma is the complicated system of the Golgi intraprotoplasmic canal. The body of the cell has a large dendritic trunk which extends toward the periphery of the cortex, basilar dendrites which extend toward the medullary substance, and protoplasmic processes which are oblique or horizontal upon the sides of the cell. The axones are large and follow a descending course. They arise from the inferior surface of the cell bodies, become incorporated in the radial fasciculi of the cortex, and thus reach the medullary substance. The axone gives off four or five collaterals which follow a more or less horizontal course.

In addition to the pyramidal cells there are other cellular elements which have short axones and belong to the Golgi type II. They are less common in this than in the second layer. Two types of these cells may be distinguished: (a) Stellate cells whose axones ascend and give off collaterals

to the second and third layers; and (b) much larger triangular cells provided with an ascending axone which takes a horizontal course in the first portion of its ascent and finally forms a diffuse terminal arborization in the second and third layers. The cells in this stratum have double brush dendrites which are very numerous especially at the level of the medium sized pyramidal cells.

Another variety of cells consists of those large elements whose axones are short and resolve themselves into pericellular nets about the cells of the second and third strata. A few of the cells of Martinotti are scattered among the pyramidal elements.

Layer of Stellate or Granular Cells.

Immediately beneath the layers of large and medium-sized pyramidal cells is a stratum containing a number of small monopolar stellate cells belonging exclusively to the Golgi type II. In addition to these cells there are some small pyramidal elements of the ordinary type whose axones pass into the medullary substance. A few large pyramidal cells are scattered throughout this layer. The chief constituents of this stratum may be classified in three groups:

1. Pyramidal cells of medium and small size resembling in all respects similar cells of the neighboring zones.
2. Triangular, stellate, ovoid or semilunar cells of considerable size.
3. A large number of small cells more or less disposed in vertical columns. These are the *granule cells*, some of which are pyramidal in shape, while others are polygonal.

All of the cells entering into this layer may be subdivided into cells having long or short axones.

CELLS OF THE STELLATE LAYER HAVING LONG AXONES. In this group are included both small and medium-sized pyramidal cells.

The small pyramidal cells have a large number of basilar dendrites which ramify a short distance from the cell body and do not pass beyond the limits of the stellate layer. The cytoplasmic trunk extends toward the periphery in a straight line and gives off numerous collateral branches toward this area. After attaining the plexiform layer it divides here into a small

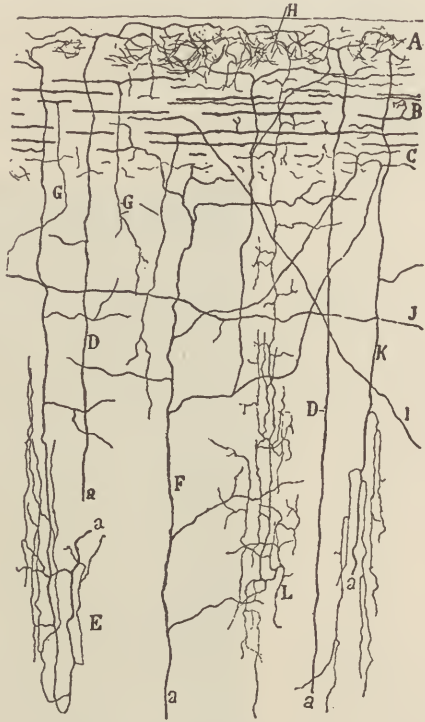


FIG. 487.—Plexiform layer and fibers of Martinotti of the cerebral cortex; in a one-month old infant. Golgi's method. (Cajal.)

A—External stratum of 1st layer. B—Middle stratum. C—Internal stratum. D—Large fibers of Martinotti. E—Fibers arranged in fasciculi of vertical collaterals. F—Fibers with rich arborization. G—Collaterals of tangential fibers. H—Terminal arborization. I—Upper branches of the axis cylinder of a cell with double brush protoplasm. J—Axone to tangential layer. a—The point where the axis cylinder starts. K—Deep tangential fiber. L—Arborization.

number of terminal branches. The axone leaves the base of the cell body, descends vertically into the sixth layer and then enters the medullary substance immediately after it receives a thin myelin sheath.

The medium-sized pyramidal cells are never entirely absent from the stellate layer of the cortex, although their number is usually small and variable in different regions of the pallium. In size, shape and disposition of their parts they are identical with the medium-sized pyramidal cells of the third layer, and need no further description.

CELLS WITH SHORT AXONES. These cells are much more numerous than the cells having long axones. They give this stratum of the cortex a somewhat

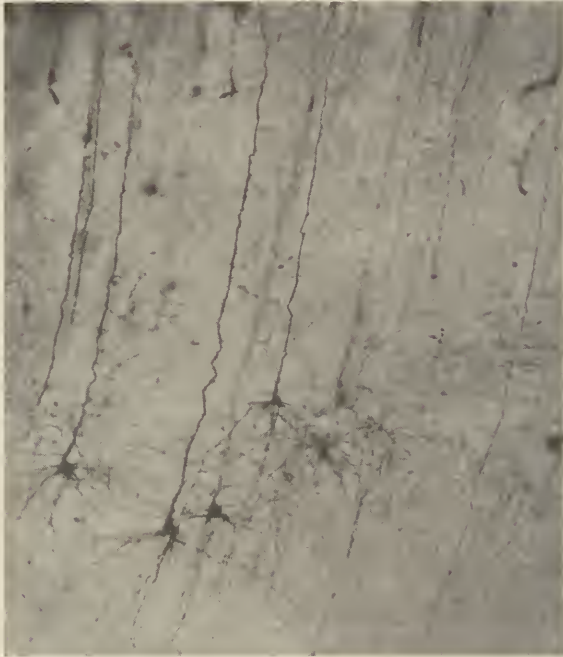


FIG. 488.—The largest pyramidal cells of the third cortical layer showing the long apical process with gemmules and numerous basal dendrites. (Starr.)

granular appearance. Among these cells are recognized stellate or fusiform elements whose axones ascend and ramify in long horizontal branches.

Some cells have ascending axones which extend a short distance to ramify in the stellate layer. The axones of these cells ascend as far as the first and second layers, where they break up into end branches.

The stellate layer of the cortex is of particular importance, as it constitutes an intermediary zone whose cells give off a great number of short axones and thus serve as associating units in the cortical mechanism. In this light the layer of stellate cells in the cerebral cortex takes its chief importance from the fact that it determines the majority of interlaminar associations carried on in this part of the brain.

The Layer of Large Internal Pyramidal Cells—Giant Cells. The sixth layer contains some of the largest cells in the nervous system. For this reason certain of them are known as the *giant pyramidal cells* or *cells of Betz*. They appear to be elements which have migrated inward from the third layer to form the sixth layer, having passed in their migration through the intervening stellate layer. The giant cells which are the characteristic feature of the motor area of the cortex, do not form an uninterrupted stratum, but appear in clusters of five or six. The arrangement and shape of the large internal pyramidal cells vary in different areas of the cortex and seem to be dependent upon the functions to which the cells are related. The cells may be isolated or in clusters. In this stratum of the cortex there are two main types of cellular elements depending upon the length of the axones. The internal large pyramidal cells vary in size from 60 by 35 to 40 by 22 micra.

CELLS HAVING A LONG AXONE. These cells comprise both large pyramidal cells and pyramidal cells of medium size. The *giant pyramidal cells* or *cells of Betz* of the motor area are recognized by the size of their basal dendrites and the large number of the Nissl bodies in their cytoplasm. One of their distinguishing features is the length of the basilar dendrites which ramify in the greater portion of the fifth and sixth layers. Their dendritic trunks extend toward the periphery and bifurcate at a short distance from their origin, where they break up into rich end arborizations in the plexiform layer. The axones of these cells give off numerous collaterals (usually four to eight in number or even more). These are given off in the sixth layer and ramify among the other pyramidal cells of the same kind. From this point the main axone may be followed into the medullary substance. The large pyramidal cells contain neurofibrils which are numerous and extremely well developed. They are always pyramidal in outline and vary in the measurements from 60 by 25 to 35 by 17 micra, according to the areas in which they appear. Another characteristic of the large pyramidal cells is the fact that the nucleolus contains a number of spherical bodies. Pyramidal cells of medium size, although much smaller, do not differ in any marked particular from the large pyramidal cells.

CELLS HAVING A SHORT AXONE. Several types of these cells are scattered among the medium-sized and large pyramidal cells.

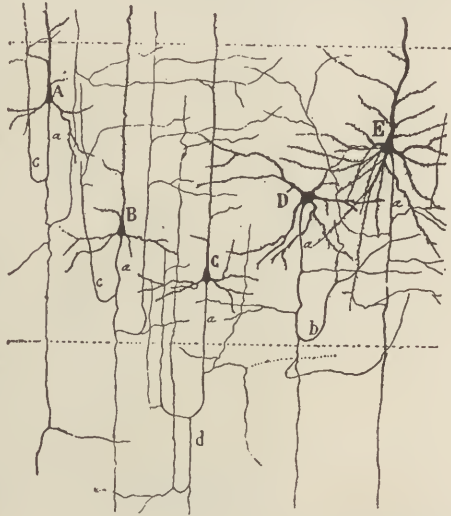


FIG. 489.—Cells with long axis cylinders of the fourth layer taken from different points of the human motor cortex. Golgi's method. (Cajal.)

A, B, C—Small pyramidal cells. D—Stellate cell with long axis cylinder. E—Large pyramidal cell. a, d—Axis cylinder. b, c—Large recurrent collaterals.

(a) Cells having an ascending axone. These cellular elements are stellate, triangular or fusiform, and occur in considerable numbers. Their dendrites do not leave the sixth layer. The axones are ascending and give rise to terminal arborizations occupying horizontal positions in their own layer and in the deeper layers.



FIG. 490.—A large cell of the third layer, showing the axone dividing into secondary and tertiary branches. Golgi type II cell. (Starr.)

(b) Fusiform or spindle-shaped cells with long ascending axones. These cells are peculiar in the fact that their axones extend as far as the plexiform layer.

(c) Arachniform cells and cells having double brush dendrites. These cells are identical in all particulars with the cells described in the second layer.

In addition to these elements some cells of Martinotti are also found in the layer of large internal pyramidal cells.

The Layer of Fusiform Cells. These cells correspond in their general features to the third layer of more or less polymorphous cellular elements. In some convolutions these cells appear in two secondary layers which are not difficult to recognize on account of the extensive plexus interpolated between them. In other regions of the brain, however, they appear as a single layer. The cells are medium-sized pyramidal elements together with triangular cells, inverted pyramidal cells and cells having a fusiform shape. Some of them have long axones, especially the medium-sized pyramidal cells. The medium-sized pyramidal cells resemble the type described in the other layers. They present a long dendritic trunk which has several

dendritic branches. Their axones enter the medullary substance and give off five or more collaterals in the sixth and seventh layers. The triangular cells possess a dendritic process which extends as far as the plexiform layer. Their bodies instead of giving rise to several basilar dendrites are connected with a single long protoplasmic extension which descends and forms end



FIG. 491.—Deep giant pyramidal cell, or Betz cell of the ascending frontal convolution; child of three years. Golgi's method. (Cajal.)

a—Axis cylinder. *c*—Collaterals. *d*—Long basilar dendrites. *e*—Protoplasmic end brush.

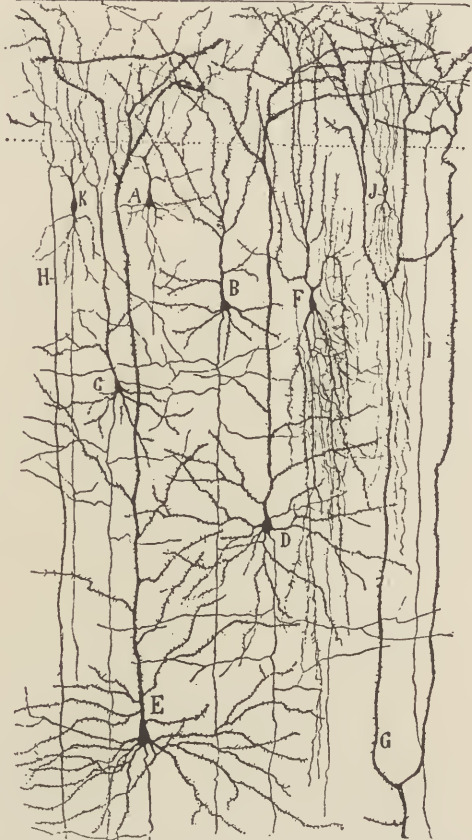


FIG. 492.—First, second and third layers of the ascending frontal convolution; one-month old infant. Golgi's method. (Cajal.)

A, B, C—Small pyramidal cells. *D, E*—Medium-sized pyramidal cells. *F*—Cell with a double brush protoplasm whose axis cylinder forms pericellular nets. *G*—Protoplasmic trunk proceeding from a large pyramidal cell of the fourth layer. *H, I*—Dendritic trunk-ends belonging to cells of the fifth and sixth layers. *J*—Small cells with double brush dendrites. *K*—Fusiform cell with long axis cylinder.

arborizations in the deepest layers. Their axones descend into the medullary substance.

The fusiform layer is deep in the regions corresponding to the axis of the convolution. In the depths of the fissures it is narrow and often mingles with the adjacent layer. The majority of cells are fusiform and arranged in vertical rows separated by the large fasciculi of the medullated substance.

Many of the cells are of the distinct pyriform outline and have two dendritic processes, one of which is vertical and long, ascending as far as the



FIG. 493.—Pyramidal cell of the brain of a rabbit. Golgi's method. (*Cajal*.)

a—Basilar protoplasmic branches. *b*—Dendritic trunk and its branches. *c*—Collaterals of axicylinder. *e*—Long axis cylinder. *l*—The white matter. *P*—Dendritic arborization.

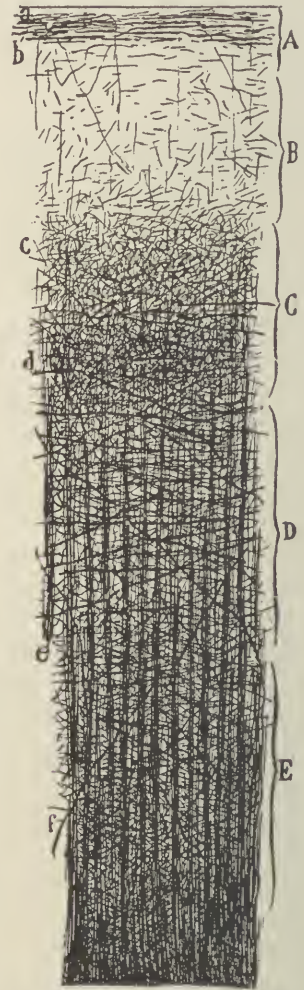


FIG. 494.—Section of a motor convolution in man. Weigert-Palm method. (*Cajal*.)

A—Plexiform layer or tangential fibers. *B*—Layer of small pyramidal cells. *C*—External portion of sensory plexus or line of Gennari. *D*—Middle plexus. *E*—Deep plexus. *a*—Sub-meningeal border having no myelin fibers. *b*—Tangential fibers. *c*—End plexus for the medium-sized pyramidal cells. *d*—Horizontal fibers. *e*—Radiate or vertical fasciculus. *f*—Oblique sensory fibers.

plexiform layer, while the other descends and occasionally divides into several branches.

Some of the cells are stellate, with short ascending axones which may ramify in the neighborhood of their origin. In other cases the axones ascend for several layers to terminate in a rich arborization. These cells seem to be related to those described by Martinotti.

The following tabulation gives in summary the types of nerve cells found in the cerebral cortex.

TABULATION OF CORTICAL CELLS AND THEIR PROCESSES

Layer of cortex	Types of cells with short axones	Types of cells with long axones	Dendrites of the cells with long axones	Long axones
1. Plexiform layer.	1. Small and medium-sized triangular, polygonal or ovoid cells. Confined to plexiform layer. Axone parallel with surface of cortex.	1. Horizontal, bipolar, stellate or triangular cells of varying size.	Short and ramifying in plexiform layer.	Extend horizontally through the plexiform layer. So-called "tangential fibers."
2. Layer of small pyramidal cells.	1. Large pyramidal, polygonal or ovoid cells. Axones extend to plexiform layer. 2. Small ovoid or pyriform cells. Axones confined to this layer.	1. Small pyramidal cells. 2. Cells of Martinotti.	Basilar dendrites ramify in second layer. Apical dendrites in plexiform layer. All dendrites in second layer.	Axones traverse second layer, enter radiations and medullary substance as fine fibers. Axones ascend to end in plexiform layer.
3. Layer of medium-sized pyramidal cells.	1. Stellate cells whose axones ascend to the second layer. 2. Large triangular cells whose axones enter the second layer.	1. Medium-sized pyramidal cells 16×12 micra. 2. Cells of Martinotti (few in number).	Basilar dendrites ramify in third layer. Apical dendrites in plexiform layer. Martinotti dendrites confined to third layer.	Axones descend to enter radiations and medullary substance.
4. Layer of large external pyramidal cells.	1. Stellate cells whose axones ascend to the second layer. 2. Large triangular cells whose axones enter the second layer.	1. Large pyramidal cells 35×17 to 28×22 micra. 2. Cells of Martinotti (few in number).	Basilar dendrites ramify in fourth layer. Apical dendrites in plexiform layer. Martinotti dendrites confined to fourth layer.	Axones descend to enter radiations and medullary substance. Martinotti axones ascend to end in plexiform layer.
5. Layer of stellate cells "granular layer."	1. Large stellate cells whose axones ascend to layers immediately above. 2. Small stellate cells whose axones enter layers below and above.	1. Small pyramidal cells. 2. Medium-sized pyramidal cells (few in number).	Basilar dendrites ramify in same layer. Apical dendrites extend toward plexiform layer. Basilar dendrites ramify in adjacent layers. Apical dendrites extend to plexiform layer.	Axones of both types of pyramidal cells extend into the medullary substance.

Layer of Cortex	Types of cells with short axones	Types of cells with long axones	Dendrites of the cells with long axones	Long axones
6. Layer of large internal pyramidal cells.	1. Stellate, triangular or fusiform cells whose axones ramify mostly in this layer.	1. Large or giant pyramidal cells (60×35 to 40×22 micra). In motor area the giant cells of Betz.	Basilar dendrites ramify in same and adjacent layers. Apical dendrites extend to plexiform layer.	Axones descend and enter medullary substance.
	2. Fusiform or stellate cells whose axones are long and extend to plexiform layer.	2. Medium sized pyramidal cells.	Basilar dendrites ramify in same layer. Apical dendrites extend to plexiform layer.	Axones descend and enter medullary substance.
	3. Arachniform cells whose axones are very slender and descend into the subjacent layer.	3. Triangular cells.	Apical dendrites ascend to plexiform layer. Dendrites in same layer.	Axones descend and enter medullary substance.
7. Layer of fusiform and spindle-shaped cells.	4. Cells of Martinotti.			Axones ascend to plexiform layer.
	1. Fusiform cells whose axones ascend and descend through adjacent layers.	1. Small pyramidal cells.	Basilar dendrites ramify in this layer. Apical dendrites ascend to plexiform layer.	Axones descend into medullary substance.
	2. Stellate cells whose axones ascend through several layers.	2. Cells of Martinotti.	Dendrites ramify in same layer.	Axones ascend to plexiform layer.

Neuroglia of the Cerebral Cortex. The neuroglial cells of the cerebral cortex present themselves as two types; the breviradiate cells whose prolongations are short and largely confined to the gray matter, and the longiradiate cells whose prolongations are long.

The *longiradiate cells* are confined almost exclusively to the white matter, although some of their processes penetrate for a distance into the gray substance.

The *breviradiate cells* are most numerous in the plexiform layer. Many of the neuroglial cells in the deeper layers are quite free of all connections, but the majority are attached to special processes of the capillaries, small arterioles and veins. In the deeper layers especially are found larger neuroglial elements known as the *deep astrocytes*.

THE WHITE MATTER OF THE CEREBRAL CORTEX

The axones entering into the formation of the cerebral cortex dispose themselves in such a way as to make possible recognition in several distinct layers. These are usually described as four in number: (1) The outermost or zonal layer; (2) the supraradiary layer; (3) the layer of Baillarger, and (4) the radiary layer.

The Zonal Layer. This layer consists of an outer fiberless area of small dimensions, and an inner tangential zone. In the fiberless layer there are a few isolated fibers of fine caliber passing, in the main, either vertically or obliquely. These are probably collaterals of the larger fibers in subjacent

layers. The general appearance of this portion of the zonal layer is due to the fact that it is composed largely of neuroglial cells. The tangential portion of the zonal layer, also known as the *tangential band* or *external plexus*, varies greatly in depth and in the wealth of fibers in different regions of the cortex. This variation is also noted in the several different periods of life. The fibers in the tangential band take an oblique or vertical course and make connection with the subjacent layers. Some of the elements entering into this band are collaterals, descending fibers, or end branches of ascending axones of Martinotti cells. The layer is composed of parallel rows of fibers in which three types may be distinguished: Large, non-varicose medullated fibers; large varicose fibers, and small varicose fibers. The larger fibers are probably axis cylinders of cells peculiar to the first layer, and collectively represent part of the association system of the cerebral cortex.

The Supraradiary Zone. This layer is situated immediately beneath the zonal layer of the cortex and is of varying depth in different parts of the brain. The fibers in it are mostly of fine caliber, extend in all directions and represent the axones of the small and medium-sized pyramidal cells occupying the neighboring areas. In this zone there occasionally appears a thin strip or stratum consisting of fibers which follow a horizontal course and are thick, medullated axones. This is known as the *line of Kaes and Bechterew*.

The Layer of Baillarger. This layer constitutes an important stratigraphical line of the cerebral cortex. It is easily recognized by the naked eye, but is not so clear upon microscopic inspection; and is situated midway between the surface of the cortex and the medullary substance. It appears in its greatest dimensions in the region of the calcarine fissure where it is known as the line of Gennari. In some regions, the layer has the appearance of reduplication so that two parallel streaks run together for a considerable distance. The line of Baillarger consists of a plexus of medullated fibers which extends but a short distance. These fibers are probably short axones of cells in the neighborhood, but numerous collaterals from other layers may participate in the formation of this layer. Some larger medullated nerve fibers run in all directions and their greater size increases the prominence of the line. These fibers appear to be similar to the association axones which extend horizontally across the medullary radiations at all levels.

The Radiary Layer or Radiations of Meynert. The appearance of this zone of the pallium depends upon the fact that a great number of radiate fasciculi enter or leave the cortex at this level. These radiations stand out distinctly and are in direct connection with the main portion of the medullary substance. Three varieties of fibers are recognized in the radiations: (1) Large medullated axones of even contour; (2) coarse, varicose fibers; (3) varicose fibrils.

Relations of the Cellular Strata to the Fiber Zones of the Cerebral Cortex. Although it is not possible to outline an exact relation between the several cellular layers and the fiber zones, it is advantageous for purposes of general topography to recognize the correspondence between these chief constituents of the cerebral cortex.

Without too sharp a line of demarcation, the zonal layer corresponds to the plexiform stratum, although the latter extends, for a short distance at least, into the supraradiary zone.

The stratum of small pyramidal and medium-sized pyramidal cells corresponds closely to the extent of the supraradiary zone, although it is encroached upon both at its ectal and ental margins by the plexiform stratum and the external layer of large pyramidal cells.

In the main, the external layer of larger pyramidal cells corresponds with considerable exactness to the line of Baillarger. This relation is subject to some variations in different parts of the cortex, especially in those areas where the line of Baillarger becomes unusually prominent, as along the calcarine fissure, or in such portions as show a reduplication of Baillarger's line.

The radiary zone or the radiations of Meynert correspond to the cellular portion of the cortex which includes the layer of stellate cells, the internal layer of large (giant) pyramidal and medium-sized pyramidal cells, and the layer of fusiform cells.

CHAPTER XLII

THE ENDBRAIN

THE MEDULLARY SUBSTANCE OF THE CEREBRAL HEMISPHERES

Distinctive Features of the Medullary Substance of the Endbrain. The medullary substance lies immediately beneath and is surrounded by the cerebral cortex. It consists of medullated nerve fibers whose collected mass forms a dense center in each hemisphere. Upon section of the brain, the medullary substance appears glistening and white in contrast to the irregular narrow gray zone representing the cortex. Situated near the mesial and basal aspects of each hemisphere, about equidistant from the frontal and occipital poles, are several massive collections of gray matter, the *corpus striatum*. In addition to the striate body, there are several lesser collections of gray matter situated near the base of either hemisphere. In the cortex, the constituent cells and fibers are arranged in definite strata, while in the corpus striatum no such arrangement is discernible. This difference also applies to the other collections of gray matter which enter into the formation of the basal ganglia.

Fiber Constituents of the Medullary Substance. The collected mass of white matter seen upon transverse or coronal section of the brain above the level of the corpus callosum is known as the *centrum ovale*. This is an apparently homogeneous mass of medullary substance entirely surrounded by cerebral cortex. Histological examination of the white matter shows that it consists of a dense collection of medullated nerve fibers supported by neuroglia. The fibers extend in various directions and may therefore be cut in different planes. For description they may be divided into three groups: (1) *Association fibers*; (2) *commissural fibers*; (3) *projection fibers*.

The projection fibers are of two orders; (a) those which arise in cells of the cerebral cortex and proceed to some destination outside of the endbrain; (b) those which arise in some part of the neuraxis outside of the telencephalon and make their way into the hemispheres to terminate in the cerebral cortex.

The association fibers spring for the most part from the lateral aspects of the convolutions. They follow a curvilinear course passing beneath the fissures to end in the lateral wall of an adjacent convolution. Some of these fibers are relatively short; some, however, extend for a considerable distance. The short fibers connect adjacent convolutions. The long fibers establish communications between the several lobes.

The commissural and projection fibers take origin from the crest or summit of the convolutions. They make a direct course into the medullary substance.

The association fibers of the long and short varieties are easily demonstrated by the Meynert method of brain dissection which consists of a par-

tial removal of the gray substance. This reveals the arrangement of the association fibers lying beneath the cortex. For the most part the short fibers are best demonstrated in this manner, although some of the bundles of long association fibers may also be brought to light.

The disposition of the fibers in the medullary substance is governed by certain general rules. Each fiber follows the course which is the most direct line toward its destination. Fibers of the association system occupy the most superficial layers of the white substance, those having the shortest course being the most superficial. The commissural and projection fibers are arranged in discrete compact fasciculi which are more or less isolated from each other by intervening masses of association fibers. The collected bundles of

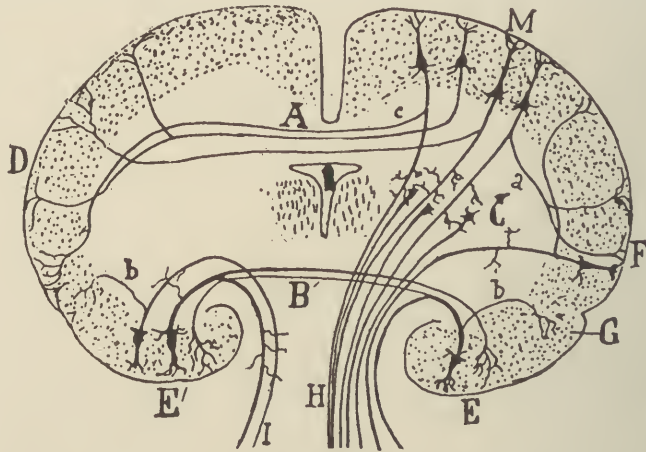


FIG. 495.—Diagram of the projection, association and commissural fibers in the brain of a rodent. (Cajal.)

A—Corpus callosum. B—Anterior commissure. C—Corpus striatum. D—Center of visual memory. E and E'—Centers of olfactory perception. F—Center of somesthetic sensibility. G—Center of olfactory memory. H—Projection system. M—Center of visual perception. I—Centrifugal olfactory fibers. a, b, c—Association fibers.

projection and commissural fibers are arranged in the form of radiations. These radiations become convergent toward the lateral border of the nucleus caudatus and the lateral angle of the lateral ventricle.

The Association Fibers. The association fibers are of three varieties: (1) The short association fibers; (2) the long association fibers, and (3) the *fibræ propriæ* of the occipital and frontal lobes.

SHORT ASSOCIATION FIBERS. These are also known as the U fibers of Meynert, the arch fibers of Arnold and the *fibræ propriæ* of the cerebral convolutions.

The short association fibers in man and the larger mammals arise and terminate in the cortex of adjacent convolutions. Their actual origin, according to Cajal, is in the small and medium-sized pyramidal cells as well as in the polymorphous cells of the cortex. Usually the axone divides into a T- or Y-shaped process and may give off several collaterals during its course. These short association fibers in some cases constitute almost

the entire amount of white matter in certain convolutions, as in the case of the gyri breves of the island of Reil, and in certain portions of the frontal convolutions.

Most of the short association fibers occupy a superficial position at the extremity of the fissures and sulci. From the fact that they pass from one convolution to the next, their general outline and direction is U-shaped and varies with the direction of the sulcus with which they are in relation. The association fibers in relation with the calcarine fissure are parallel to the vertico-transverse plane of the hemisphere. Those in relation with the temporal fissure and the collateral fissure have a sagittal direction. The fibers in relation with the fissure of Rolando and the parieto-occipital

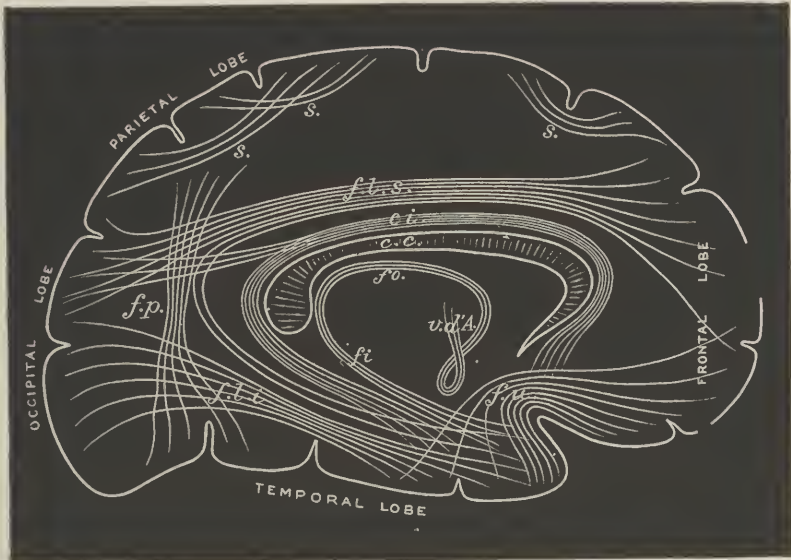


FIG. 496.—Diagram to show the general course of the association fibers of the cerebral hemisphere. (Meynert.)

s.—short association fibers, connecting adjacent gyri; f.l.s.—fasciculus longitudinalis superior; ci.—cingulum; f.p.—fasciculus perpendicularis; f.l.i.—fasciculus longitudinalis inferior; f.u.—fasciculus uncinate; fo.—fornix; fi.—fimbria; v.d'A.—bundle of Vieq d'Azyr; c.c.—corpus callosum.

fissure, are parallel to the horizontal plane of the hemisphere. In general, the direction of the association fibers which form U-shaped arches between adjacent convolutions is perpendicular to the axis of the fissure to which they are related. They are to be distinguished from the intracortical fibers of Meynert by their subcortical position and the intensity of their staining reaction. Each sulcus of the brain presents its accompanying short U-shaped association fibers which constitute a medullary stratum named according to their fissures. Thus, the short association fibers in relation with the Rolandic fissure form the *stratum Rolandicum*; those related to the calloso-marginal fissure compose the *stratum calloso-marginalis*; to the collateral fissure the *stratum collateralis*; and to the parieto-occipital fissure the *stratum parieto-occipitalis*.

LONG ASSOCIATION FIBERS. These fibers are collected into five distinct fasciculi which extend from one lobe to another; namely, the *cingulum*, the *fasciculus arcuatus* or *superior longitudinal fasciculus*, the *inferior longitudinal fasciculus*, the *fasciculus uncinatus* and the *fasciculus occipito-frontalis*.

The *cingulum* is an association bundle in the rhinencephalon bringing the first limbic convolution into relation with the second and uniting the limbic lobe with other portions of the brain.

The other four fasciculi of association fibers belong to the neopallium and connect the different lobes.

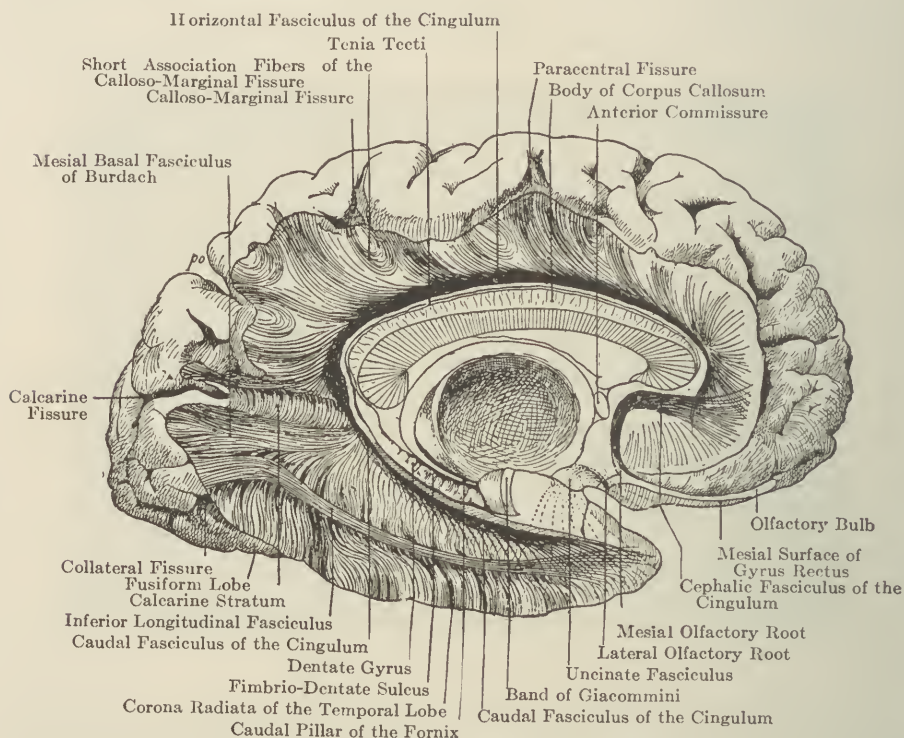


FIG. 497.—The association tracts as seen according to a dissection after the method of Meynert showing the association tracts of the white matter as seen from the mesial surface. (*Déjerine.*)

The *superior longitudinal fasciculus* connects the parietal and temporal lobes with the frontal lobe; the *fasciculus uncinatus* connects the temporal lobe with the frontal lobe; the *fasciculus longitudinalis inferior* connects the temporal and occipital lobes; and the *fasciculus occipito-frontalis* forms the connection between the temporal and occipital lobes on the one hand and the frontal lobe on the other.

The *cingulum* (the *fasciculus longitudinalis of the gyrus fornicatus* or the *fornix periphericus*) consists of a long fasciculus of rhinencephalic association fibers. It is an arched bundle which follows a sagittal direction. It is situated near the mesial surface of the hemisphere and constitutes a

large part of the medullary substance of the first and second limbic convolutions. The arch formed by the cingulum passes about the rostrum, genu and body of the corpus callosum, through the isthmus hippocampi, into the hippocampal convolution, where it sweeps downward and forward toward the tip of the temporal lobe. The origin of the cingulum is a matter of controversy, but most recent investigation seems to indicate that it consists of three separate fasciculi, the anterior fasciculus, the horizontal fasciculus and the posterior fasciculus. The horizontal fasciculus passes along the dorsal surface of the corpus callosum; it arises in the first limbic convolution which it connects with the convolutions of the orbital surface of the hemisphere. The posterior fasciculus occupies the hippocampal convolution from which it takes origin and connects this part of the brain with the lobulus lingualis and the convolutions of the temporal lobe. The anterior fasciculus is situated in relation with the genu and rostrum of the corpus callosum; it arises in the anterior perforated space in relation with the olfactory tract which it connects with the frontal lobe.

The *fasciculus uncinatus* consists of short and long association fibers of the neopallium, which connect the temporal lobe with the orbital convolutions of the frontal lobe. The anterior extremity of the fasciculus uncinatus is in relation with the anterior perforated space and the inferior surface of the putamen. Its fibers appear to arise in the gyrus rectus and in adjacent parts of the first and second orbital convolutions of the frontal lobe. Caudally, the fibers of the fasciculus uncinatus come into relation with the temporal lobe and the nucleus amygdalæ. This fasciculus is often affected in lesions involving the island of Reil and the external capsule. Its fibers degenerate in part toward the temporal pole and in part toward the orbital convolutions of the frontal lobe.

The *superior longitudinal fasciculus* (*fasciculus arcuatus* of Burdach) is situated near the external surface of the hemisphere, in contrast to the cingulum, which is situated near the mesial surface. It lies beneath the base of the convolutions forming the Sylvian opercula, lateral to the fibers which form the corona radiata, and at a level corresponding to the body of the corpus callosum. It presents itself in its most compact state in the region of the parietal operculum. Here it lies parallel to the superior border of the putamen. Its more superior and superficial fibers come into close relation with the circular sulcus of the island of Reil and form the more superior portions of the external capsule. At the caudal limit of the fissure of Sylvius, the fasciculus arcuatus describes a curve the concavity of which is directed ventrally to embrace the dorsal border of the putamen. Its more superficial fibers cross beneath the fasciculus uncinatus to radiate within the crest of the more ventral portion of the first temporal convolution, while the deeper fibers terminate in the dorsal portion of the first and second temporal convolutions where they intersect the fibers of the corona radiata and the radiations of the corpus callosum. The deepest fibers enter into the crest of the gyrus supramarginalis and the lateral surface of the convolutions of the occipital lobe.

The termination of the superior longitudinal fasciculus is not clearly defined. According to some authorities, the fibers end in the Rolandic operculum and also in the operculum of the third frontal convolution. The fasciculus arcuatus, therefore, constitutes a bundle of association fibers connecting the lateral surface of the temporal and occipital lobes with the convexity of the frontal lobe. The facts demonstrated by secondary degeneration and agenesis of the corpus callosum do not favor this view. It is probable that the connection determined by the superior longitudinal fasciculus is an ipsilateral one between the temporal and occipital lobes on the one hand and the frontal lobe on the other.

The *occipito-frontal fasciculus* (*fasciculus of Forel and Onufrowicz*) extends along the lateral angle of the lateral ventricle. It is situated mesial to the corona radiata, above the nucleus caudatus, below and to the outer side of the corpus callosum. It is separated from the body of the ventricle by ependymal and central gray substance. The corpus callosum separates it from the cingulum, while the base of the corona radiata is interposed between it and the superior longitudinal fasciculus. The fasciculus occipito-frontalis takes origin in the cortex of the frontal lobe, particularly in the lateral and orbital surfaces of the frontal pole. From the base of the occipito-frontal fasciculus many fibers extend in a vertico-transverse course, passing below and mesial to the base of the corona radiata to enter into the formation of the external capsule. The occipito-frontal fasciculus consists of a long bundle of association fibers which bring the occipital and temporal lobes into relation with the frontal lobe and with the island of Reil. The connection with the insula is completed by fibers which enter the external capsule. The most striking feature concerning the occipito-frontal fasciculus is its relation to the corona radiata and the lateral ventricle. It occupies a subependymal position adjacent to the body as well as to the occipital and temporal cornua of the ventricle. Unlike the other long association tracts it is situated mesial to the corona radiata.

The *inferior longitudinal fasciculus* (*faisceau sensitif of Charcot* or the *inferior longitudinal fasciculus of Burdach*) is a bundle of association fibers which follows a caudo-cephalic course. It is situated at the level of the lateral border of the temporo-occipital area and extends from the occipital to the temporal pole. This fasciculus comprises the external layer of sagittal fibers of the medullary substance in the occipital and temporal lobes, and may be easily dissected by the method of Meynert. In thickness this bundle varies considerably in different regions. In its caudal portion it becomes attenuated, and in this region it sweeps around the extremity of the occipital horn of the lateral ventricle. Along the lateral wall of the body of the ventricle it becomes considerably thickened, but is again reduced in size as it approaches its cephalic extremity in the temporal lobe. The fibers of the inferior longitudinal fasciculus arise in the pole of the occipital lobe. These fibers begin to assemble in a region caudal to the occipital horn of the lateral ventricle, where they form a slender bundle which receives a large number of incremental fibers from the cuneus, lobulus lingualis, lobulus fusiformis and

the convexity of the occipital lobe. All of the fibers in this bundle do not follow the same course. The axones arising in the ventral and lateral portions of the occipital lobe pass forward along the ventro-lateral border of the temporal horn of the ventricle; those taking origin from the dorso-lateral portion of the occipital lobe follow an oblique course from above downward along the lateral wall of the body of the ventricle. The fibers arising from the cuneus extend obliquely forward and downward mesial to the mesial wall of the occipital horn of the ventricle and ultimately pass beneath the floor of this portion of the ventricular chamber to become confluent with the other bundles entering into the fasciculus. In the temporal lobe the inferior longitudinal fasciculus gives off many fibers to the several convolutions. The fibers of its anterior portion terminate in the hippocampal gyrus, the lobulus fusiformis and the three temporal convolutions. The majority of its fibers pass to the first temporal gyrus and extend to the temporal pole where they interlace with fibers of the superior longitudinal fasciculus and fasciculus uncinatus.

Long association fibers of the occipital lobe have been observed which serve to bring the different parts of this region into association with each other. Five more or less distinct bundles form a complex intrinsic occipital association system. These bundles are: (1) The *stratum calcarinum*, occupying the most mesial position; (2) the *vertical occipital fasciculus of Wernicke*, which occupies a lateral position; (3) the *transverse fasciculus of the lobulus lingualis of Vialet*, occupying a basal position; (4) the *transverse fasciculus of the cuneus*, extending through the dorsal portion of the occipital lobe, and (5) the *fasciculus of the cuneus of Sachs*.

The fibers constituting the vertical occipital fasciculus, the fasciculus of the cuneus and the stratum calcarinum, in general, pursue a vertical course. They establish connections between the dorsal and ventral aspects of the occipital lobe and the intervening levels between these surfaces. The transverse fibers of the fasciculus transversus cunei and the fasciculus transversus lobuli lingualis effect connections between the mesial and lateral surfaces of the occipital lobe.

The *stratum calcarinum* is a thick layer of fibers which connects the superior and inferior lips of the calcarine fissure. The shorter fibers in the fasciculus occupy a more superficial position and establish connections with the deeper parts of the two lips of the calcarine fissure, while the long fibers connect the mesial surface of the cuneus with the ventro-mesial surface of the lingual lobule.

The *vertical occipital fasciculus (fasciculus occipitalis perpendicularis of Wernicke)* consists of a thick layer of occipital association fibers which establish communication between the dorsal and ventral aspects of this lobe. It serves to connect the first and third occipital convolutions with the lobulus fusiformis. In its course it comes into relation with the gyrus supra-marginalis, and here may be confused with the descending fibers of the longitudinal fasciculus of Burdach.

The *transverse occipital fasciculus of the cuneus (stratum cunei transversum)* connects the convexity of the cuneus with the lateral surface of the

occipital lobe along its ventro-lateral aspect. The fibers take origin in the superior lip of the calcarine fissure and pass transversely in a lateral direction. They finally radiate to end in the cortex of the convexity of the occipital lobe. Some of the more ventral fibers of this fasciculus pass obliquely forward and end in the superior parietal convolutions and in the angular gyrus.

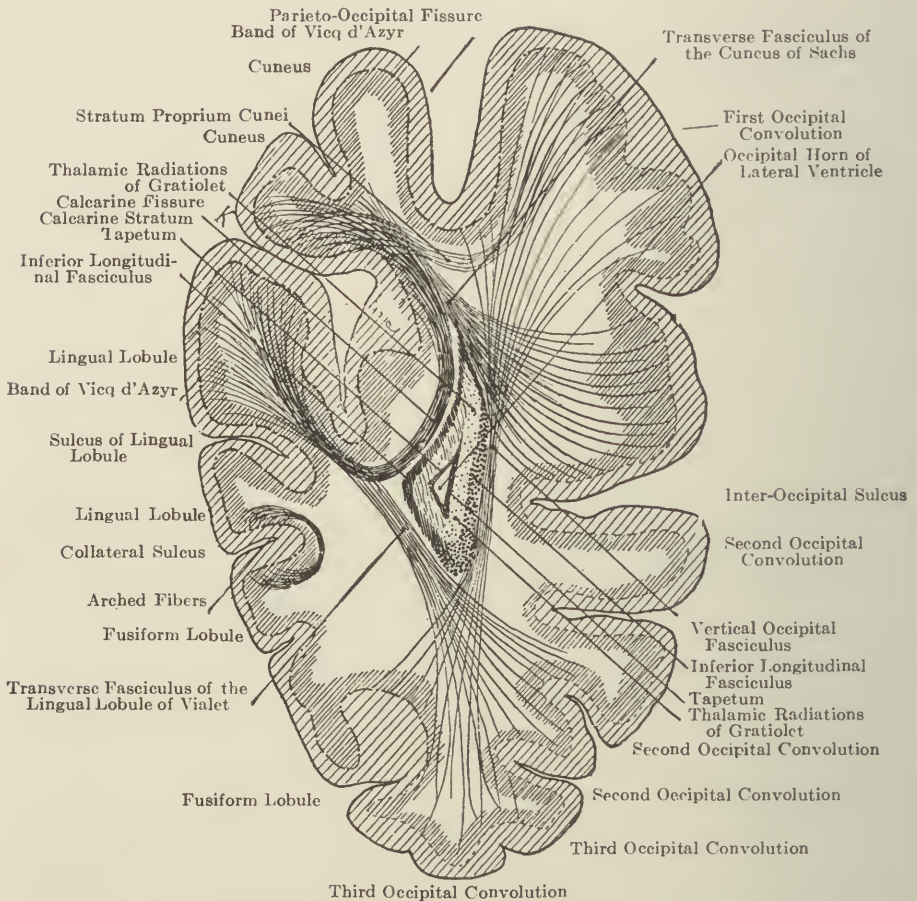


FIG. 498.—Vertico-transverse section of the left occipital lobe showing the origin and course of the association fibers characteristic of the occipital lobe. (Semi-schematic.) (Déjerine.)

The *transverse occipital fasciculus of the lingual lobule of Violet* bears the same relation to the lobulus lingualis that the transverse occipital fasciculus of the cuneus bears to that lobule. It rises in the inferior lip of the calcarine fissure, extends transversely outward, passes beneath the inferior longitudinal fasciculus and the occipital horn of the lateral ventricle. Here it begins to radiate and terminates ultimately in the cortex of the second and third occipital convolutions.

The *fasciculus of the cuneus* (*stratum proprium cunei of Sachs*) consists of vertical fibers similar to those in the *stratum calcarinum*. The fibers take origin in the superior lip of the calcarine fissure and extend downward and outward to terminate in the first occipital convolution.

The *association fibers of the frontal lobe*, establishing communication between the several frontal convolutions, although present, have not the distinctness of those observed in the occipital lobe. Bundles of fibers extending for a considerable distance both vertically and transversely may be discerned in a more diffuse arrangement of the medullary substance in this part of the brain. These long association fasciculi serve to connect the mesial with the lateral surface and also the convolutions near the convexity with those situated along the base.

The Commissural Fibers. The system of commissural fibers, which plays so important a rôle in the formation of the medullary substance of the endbrain, connects the two hemispheres with each other. It is an inter-hemispherical association system in contradistinction to the association fibers already considered which compose an intra-hemispherical system. The inter-hemispherical system comprises the *corpus callosum*, the *anterior commissure* and the *transverse commissure* of the fornix.

THE CORPUS CALLOSUM. The inter-hemispherical fibers which enter into the formation of the corpus callosum are collected to form a massive body situated in the depths of the superior longitudinal fissure and connecting one hemisphere with the other. The cephalic and caudal extremities are situated about equidistant from the frontal and occipital poles respectively. In form, the corpus callosum is an arched structure which upon sagittal section through the superior longitudinal fissure presents a *body* (*truncus corporis callosi*), a *splenium* or thickened caudal portion, a *genu* or cephalic flexure, and a *rostrum*, its ventral termination.

The body of the corpus callosum is convex upon its dorsal surface and partly free except for a thin covering, the *indusium griseum*, in which are contained the *striæ medullares longitudinales*. The mesial *striæ* are known as the *nervi Lancisii*; the lateral *striæ* as the *tenia tectæ*.

The ventral surface of the corpus callosum is concave and, in its caudal portion, in contact with the body of the fornix. In its more ventral portion it is covered by the *septum pellucidum*. Its length is 7 cm. It has its greatest thickness at its caudal extremity where its diameter is 8 mm. Its greatest width is situated in this position and measures about 20 mm. The thickened cephalic end of the corpus callosum is the *genu* which is flexed forward and then backward to terminate in the sharply curved and tapering *rostrum* whose attenuated extremity is continued ventrally into the *lamina terminalis*. The caudal extremity of the corpus callosum is the *splenium* which overlies the pineal body and the superior colliculi of the midbrain.

Relations of the Corpus Callosum. The convex dorsal surface of the corpus callosum is free except at its caudal extremity where it comes into contact with the *falx cerebri*. Laterally it is partially concealed by the *callosal gyrus* from which it is separated by the *callosal fissure*.

The rudimentary gray matter of the indusium and the two sets of striæ already mentioned represent the remnants of an atrophic convolution which has gradually been reduced in prominence as a result of the progres-

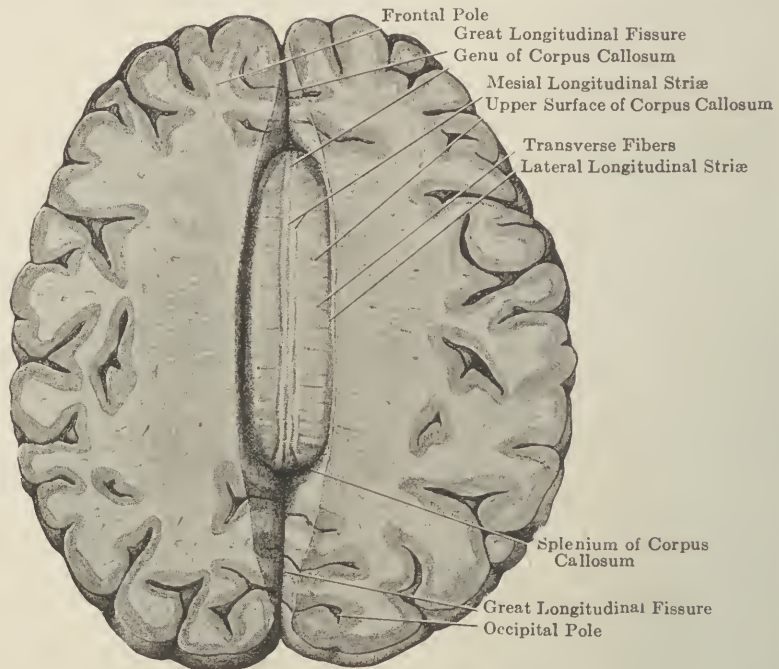


FIG. 499.—Section showing corpus callosum.

sive development of the corpus callosum in mammals. The mesial striæ may be traced forward around the genu and rostrum to the gyrus subcallosus. The lateral striæ may be followed into the area parolfactoria and the anterior perforated space. Caudally these striæ as well as the indusium griseum pass around the splenium into the gyrus dentatus.

The ventral surface of the corpus callosum presents considerable transverse striation and forms the roof of the frontal cornu and body of both lateral ventricles. The difference in length between the mesial surface of the hemispheres and the corpus callosum determines the greater assemblage of fibers in the genu and the splenium. In these two areas the fibers are consolidated to form the most massive parts of the corpus callosum. At the lateral margins of the corpus callosum the nerve fiber bundles no longer maintain their compact form, but begin to radiate in all directions toward the cortex. This radiation constitutes the *radiatio corporis callosi*. The axones in this radiation intersect those of the corona radiata. The fibers constituting the inner portion of the body and dorsal portion of the splenium form a thin but definite sheet of fibers, the *tapetum*, which forms part of the lateral wall of the occipital horn of the ventricle and constitutes an important boundary of the temporal horn and body of the ventricle.

The nerve fibers which enter into the formation of the more cephalic portion of the genu sweep forward and outward on either side as a distinct band extending to the frontal pole of each hemisphere. Together these two

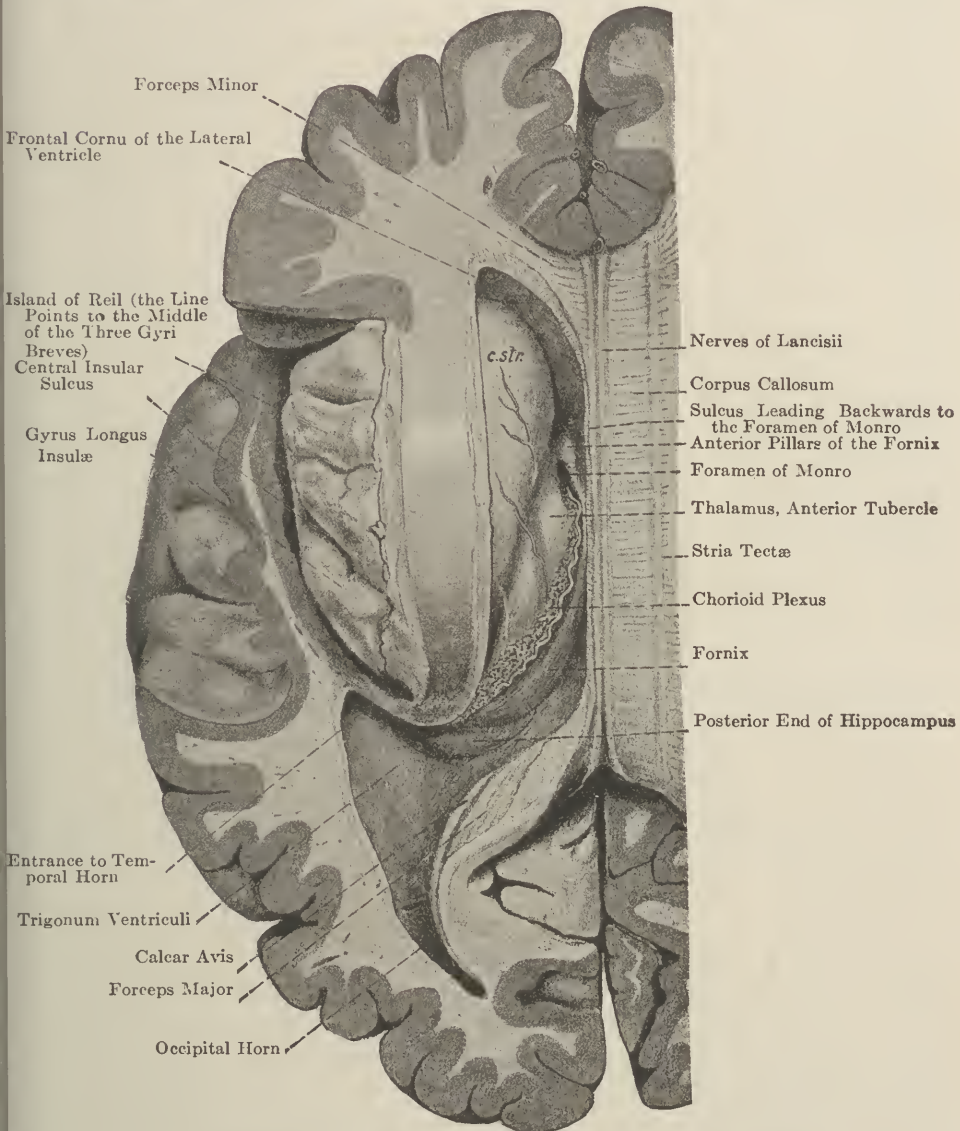


FIG. 500.—View of the lateral ventricle from above. (G. D. Thane.)

c.str.—Caudate Nucleus of Corpus Striatum.

The preparation was made with the brain in situ (hardened). The skull cap and membranes having been removed, the brain was sliced down to the level of the corpus callosum. The left lateral ventricle was then opened by cutting away its roof, and the island exposed by slicing away the opercula. The drawing is made from a photograph.

bands constitute the *forceps anterior* or *minor*. The fibers constituting the larger part of the splenium also spread out as two symmetrical bands in each hemisphere which curve outward and backward toward the occipital

pole. Together these fasciculi which pass from one hemisphere to the other by means of the splenium form the *forceps posterior* or *major*.

Fibers of the Corpus Callosum. The fibers of the corpus callosum, in all probability, represent the axis cylinders of small and medium sized pyramidal cells. Some evidence indicates that the collaterals from the long association fibers as well as from the projection fibers may enter into the formation of the corpus callosum. The callosal fibers arise in the several areas of the cortex, converge in a radial fashion toward the lateral angle of the lateral ventricle, and here become united in compact fasciculi forming the splenium, body, genu and rostrum of the corpus callosum. The nerve fibers forming the body of the corpus callosum arise from the caudal portion of the frontal lobe, from the entire parietal lobe, from the caudal portion of the temporal lobe, and to some extent probably from the insula. Fibers entering the body also arise from the first limbic convolution, the first frontal convolution, the paracentral lobule, the precuneus, the first parietal convolution and the precentral convolution. These fibers occupy a ventral position. Between the dorsal and ventral layers forming the body of the corpus callosum are fibers arising from the second frontal convolution, the second parietal convolution and the first temporal convolution. In the trunk of the corpus callosum the fibers are arranged in several superposed laminæ giving the structure a more or less distinct stratification.

The fibers entering the genu of the corpus callosum arise from the lateral, orbital and mesial surfaces of the frontal lobe and converge toward the ventro-cephalic angle of the lateral ventricle. They arise from the first, second and third frontal convolutions. Their collected mass in the two hemispheres before entering the genu constitutes the *forceps anterior*.

The fibers entering the rostrum of the corpus callosum arise from the orbital surface of the frontal convolutions. Some of them also enter this part of the corpus callosum by way of the external capsule. They are separated from the inferior portion of the internal capsule by means of the bridge of gray substance which connects the head of the caudate nucleus with the putamen.

The fibers in the splenium of the corpus callosum comprise three distinct segments, a dorsal segment which represents the extreme caudal division of the corpus callosum, a ventral segment, the splenium proper, and an intermediate segment, the so-called *genu posterior* of the corpus callosum. The fibers of the ventral and intermediate segments of the splenium are disposed in the same manner as the fibers entering the body. They take origin in the parietal lobe. The fibers entering the dorsal segment upon reaching the splenium are grouped in two fasciculi, the *ventral fasciculus* also known as the *fasciculus minor of the forceps* and the *dorsal fasciculus* or *fasciculus princeps of the forceps*. The minor fasciculus of the forceps receives its fibers from the lobulus lingualis and also from the second and third occipital convolutions. Some of its fibers arise in the first occipital convolution and the cuneus. The fibers in the dorsal fasciculus—the fasciculus princeps of the forceps—pass inward in a sagittal direction. They are reinforced by fibers

from the lateral surface of the occipital horn of the lateral ventricle, from the cuneus and the occipital convolutions. Still other fibers arise in the precuneus, the first parietal convolution and the angular gyrus. The fibers in the corpus callosum, in the main, establish interhemispherical connections between identical areas in the two hemispheres.

THE ANTERIOR COMMISSURE. As part of the commissural system of the brain, the anterior commissure is more primitive than the corpus callosum. It appears in the lower vertebrates when the corpus callosum is not present. The anterior commissure is a fasciculus of medullated fibers more or less cylindrical in outline. Its mesial portion is free and appears at the cephalic extremity of the third ventricle. It is situated at the level of the ventral angle of the septum pellucidum, with its caudal surface covered by the central gray substance of the third ventricle and crossed obliquely by the anterior pillars of the fornix. With the pillars of the fornix it forms a triangular space, the *recessus triangularis*. The ventral surface of the anterior commissure is covered by the medullary substance entering into the formation of the rostrum of the corpus callosum. Upon sagittal section it appears oval in outline, its vertical diameter measuring 5 mm. and the horizontal diameter 3 to 4 mm.

The anterior commissure comprises a neopallial and an olfactory portion. The olfactory portion is small in man but attains large proportions in macromammals. It contains commissural fibers which connect the two olfactory lobes, as well as fibers which connect the olfactory lobe of one side with the temporal lobe of the opposite side. The origin of the neopallial portion of the anterior commissure has not yet been definitely determined. It has been ascribed to the occipital, temporal and limbic lobes and even to the island of Reil. These interpretations concerning its origin, however, are open to objection, and it seems wiser to leave the final decision of this matter to the results of further investigation. In general this division of the anterior commissure connects neopallial portions of the cerebral hemispheres. Temporal fibers in the anterior commissure constitute its greater portion. These fibers pass horizontally outward beneath the lenticular nucleus as far as the mesial border of the putamen, where they turn caudally and continue beneath the lenticular nucleus. On transverse section they appear as an oval bundle which ultimately turns abruptly downward to disappear in the medullary substance of the temporal lobe.

THE HIPPOCAMPAL COMMISSURE. The hippocampal commissure is a triangular lamina of medullary substance composed of transverse fibers. It is situated between the posterior pillars of the fornix as they converge to form the body of the fornix. The commissure is bounded caudally by the splenium and dorsally by the ventral surface of the body of the corpus callosum. It is also known as the *psalterium* or *lyra Davidi*. A small horizontal space, *cavum psalterii* occasionally intervenes between the ventral surface of the corpus callosum and the lyra. This space has no connection with the ventricular system of the endbrain and results from an incomplete union between the lyra and the corpus callosum. The hippocampal

commissure connects the two hippocampal convolutions. It also contains some fibers which undergo decussation and then join the longitudinal strands of the fornix and proceed toward the thalamus.

Projection Fibers of the Cerebral Cortex. The projection fibers entering into the formation of the medullary substance of the cerebral hemispheres consist of medullated axones which connect the cerebral cortex with the segmented portion of the neuraxis. They represent suprasegmental connections and are of two types—those which take origin in the cortex and terminate in the segmented portion of the nervous system; and those which arise in the segmented part of the central nervous system and terminate in the cortex. In other words, the suprasegmental fibers of the cerebral cortex are both afferent and efferent in their course and function.

The projection fibers connected with the rhinencephalon constitute the *archipallial projection system*; those connected with the remainder of the cortex represent the *neopallial projection system*. Collectively, the projection fibers serve to connect the cerebral cortex with the spinal cord, the medulla, pons and cerebellum, the midbrain and interbrain.

The projection system of the rhinencephalon is represented by the olfactory radiations and the fornix. In man this system is but little developed. In macrosmatic mammals it attains a high degree of development.

The projection system of the neopallium is represented by the internal capsule. This portion of the brain is absent in fishes, amphibians, reptiles and birds.

NEOPALLIAL PROJECTION SYSTEM. The projection fibers of the neopallium are both corticifugal (efferent) and corticipetal (afferent). They take origin or end in the large pyramidal and medium-sized pyramidal cells of the cerebral cortex and in some of the polymorphous cells. Those of the corticipetal type arise in segmented portions of the neuraxis and ascend to various areas of the cortex. In their passage away from or toward the pallium these fibers enter into the formation of the *centrum ovale*, the *corona radiata* and the *internal capsule*. The neopallial projection fibers in their course to and from the cerebral cortex pass through the medullary substance of the hemisphere in a characteristic manner. They reach or leave the cortex in a series of radiating bundles which constitute the *corona radiata*. As they approach the ventro-mesial aspect of the hemisphere these radiating strands converge and are finally drawn together into a compact collection of fibers in relation with the optic thalamus and basal ganglia. This collection of projection fibers is the *internal capsule*. The internal capsule in this respect forms the great trunk line of conduction for impulses passing into and out of the cerebral hemisphere. The corona radiata represents the course of individual pathways which have specific localities of origin or destination in the cortex. It is readily seen that the fasciculus of projection fibers emerging from the internal capsule and destined for the frontal lobe, would diverge widely from the fasciculus which passes through the internal capsule and turns caudally to end in the occipital lobe. Intermediate fasciculi arising in or destined to areas intermediate between the occipital and frontal poles

would follow courses less divergent, making their way to the parietal and temporal regions. The corona radiata may for this reason be likened to the leaves of an opened fan the handle of which is represented by the internal capsule.

Segments of the Corona Radiata. The fasciculi entering into the corona radiata may be divided according to their origin, their direction and the length of their fibers, into four groups; namely, the cephalic, the superior, the posterior and the inferior segments. These four segments pursue a curvilinear course along the lateral angle of the floor of the lateral ventricle and its cornua. They have a certain number of relations in common. Their mesial surfaces curve about the fibers of the corpus callosum and the occipito-frontal fasciculus, which separates this surface from the ependyma of the ventricle. The lateral surface is in continuity, without marked differentiation, with the medullary substance of the centrum ovale. At the base of the corona radiata each of the segments is in contact with the fasciculus

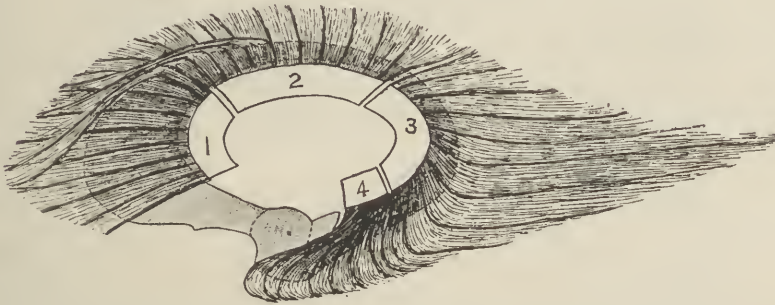


FIG. 501.—The different segments of the corona radiata and their connection with the corresponding segments of the internal capsule. Schematic representation. (Déjerine.)

1. Cephalic segment. 2. Superior segment. 3. Posterior segment. 4. Inferior segment. The caudate nucleus is tinted gray.

longitudinalis superior and is crossed by some of the fibers of the occipito-frontal fasciculus.

The *anterior segment of the corona radiata* consists of fibers from the lateral, mesial and orbital surfaces of the frontal lobe as well as from the frontal pole. Its general direction is downward, backward and inward. The fibers present a marked obliquity in their approach to the internal capsule. This segment of the corona comprises a mesial stratum consisting of fibers arising in cells in the mesial surface of the hemisphere and a lateral stratum derived from the lateral hemispherical surface.

The *superior segment of the corona radiata* consists of axones arising in the median portion of the hemisphere, particularly in the Rolandic convolution, and in the adjacent parietal and frontal convolutions, the paracentral lobule, the median portion of the first limbic convolution and the hippocampus. They follow a course along the lateral angle of the ventricle with a general direction downward and inward. Like the anterior segment, it presents a mesial and a lateral stratum, the mesial stratum containing fibers from the convolutions upon the mesial surface of the hemisphere, and the lateral

stratum consisting of axones which arise from cells on the lateral surface. These two strata approach each other immediately above the dorsal limits of the internal capsule, at which point they become confluent and form the trunk of the middle segment of the corona.

The *posterior segment of the corona radiata* contains some of the longest fibers entering into the projection system. The axones in it arise from the occipital pole, from the mesial, lateral and ventral surfaces of the occipital lobe, from the lobulus lingualis, the lobulus fusiformis, and from the

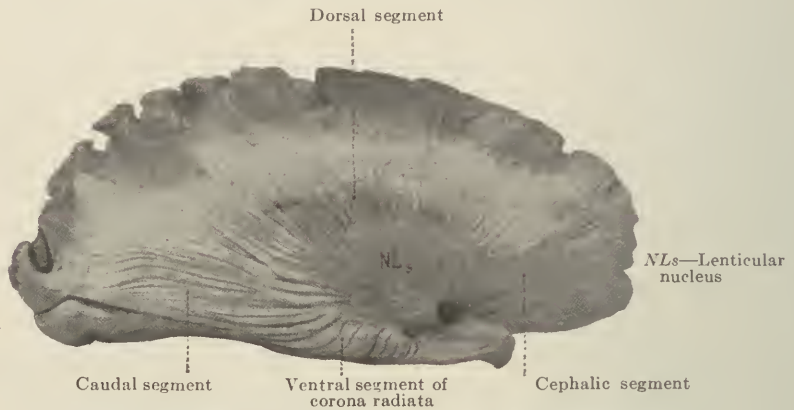


FIG. 502.—External surface of the corona radiata. (Déjerine.)

first, second and third occipital convolutions. These fibers are joined by several large radiating bundles which take origin in the precuneus, the angular gyrus, the superior parietal and inferior parietal convolutions, the supramarginal convolution and in the caudal part of the three temporal convolutions.

The general course of the fibers in the posterior segment of the corona radiata is forward, inward and downward. In the region of the body of the lateral ventricle the fibers are collected into a dense bundle which runs along the lateral wall of the ventricular cavity. In the occipital region the fasciculi of this segment surround the occipital horn of the ventricle and are separated from the ventricular ependyma by the *tapetum* and the *forceps posterior*. The trunk of this segment receives tributaries from two strata; one, the mesial stratum, which establishes connections with the mesial surface of the hemisphere, the other, the lateral stratum, which serves in similar capacity for the cortex of the lateral convexity.

The *inferior segment of the corona radiata* is in connection with the temporal lobe. Its cephalic limit is determined by the fusion between the nucleus amygdalæ and the tail of the caudate nucleus. Caudally, it is ill-defined and without line of demarcation from the posterior segment. The inferior segment of the corona receives fibers from the caudal, middle and cephalic portions of the temporal lobe, especially from the three temporal convolutions, the lobulus fusiformis and the hippocampal convolution. Some of its fibers extend to the more cephalic portion of the occipital lobe. The fasciculi of

this segment surround the floor and lateral wall of the temporal horn of the lateral ventricle. Their general direction is upward, inward and forward. In their ascent from the internal capsule the fibers of the inferior segment of the corona radiata pass between the tail of the caudate nucleus and the putamen and then along the ventral surface of the lenticular nucleus.

THE INTERNAL CAPSULE AND ITS DIVISIONS. Each of the four segments of the corona radiata has its corresponding division in the internal capsule. The anterior segment of the corona radiata is represented by the *anterior or lenticulo-caudate division of the capsule*. This is also known as the *anterior limb of the internal capsule*. The superior segment of the corona is represented by the *posterior or lenticulo-thalamic division of the capsule*. The posterior segment of the corona radiata is represented by the *retrolenticular division of the capsule*. The inferior segment of the corona radiata is represented by the *sub-lenticular division of the capsule*.

The internal capsule is a broad, compact band of nerve fibers which pass between the telencephalic ganglia and the optic thalamus. Its relations to the structures situated in this region vary considerably according to the level at which it is viewed. Its outer boundary is formed by the meso-cephalic and meso-caudal surfaces of the lenticular nucleus. Its mesial boundary is established by the head of the caudate nucleus and the optic thalamus. In passing from above toward the cerebral peduncle it comes successively in relation with the thalamus and subthalamus. That portion of the capsule in relation with the optic thalamus constitutes the *thalamic region of the internal capsule*. The portion related to the subthalamus is the *subthalamic region of the internal capsule*.

In transverse sections of the hemisphere through the thalamic region of the internal capsule this structure is revealed in its characteristic relations. Here it consists of an anterior limb, a posterior limb and a genu or angle. The two limbs meet at the genu and form an obtuse angle whose apex is directed inward.

In transverse sections of the hemisphere through the subthalamic region of the internal capsule, this structure consists of a posterior limb alone, the anterior limb and genu having disappeared due either to the termination of the fibers in the anterior limb and genu, or the shifting of their bundles into relation with the posterior limb. The space between the

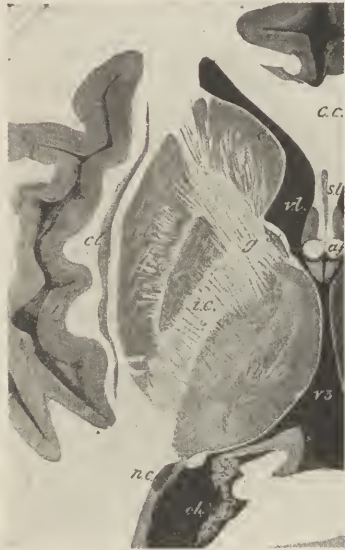


FIG. 503.—Horizontal section through part of the cerebral hemisphere. (From a preparation by S. G. Shattuck.)

v—lateral ventricle, frontal horn; *c.c.*—corpus callosum; *s.l.*—septum pellucidum; *a.f.*—anterior pillars of the fornix; *v3*—third ventricle; *th*—thalamus; *s.t.*—stria terminalis; *n.c.*—caudate nucleus; *l.c.*—lenticular nucleus of corpus striatum; *i.c.*—internal capsule; *g*—its angle or genu; *n.c.*—tail of the caudate nucleus appearing in the temporal horn of the lateral ventricle; *cl*—claustrum; *I*—insula; *ch*—choroid glands of lateral ventricle.

head of the caudate nucleus and lenticular nucleus formerly occupied by fibers of the anterior limb of the internal capsule in the thalamic region is obliterated by a fusion between the head of the caudate and the lenticular nucleus in the subthalamic region.

The *anterior limb* or *lenticulo-caudate division of the internal capsule* is situated between the head of the caudate nucleus and the cephalo-mesial surface of the lenticular nucleus. It is formed by fibers which are making a horizontal course and are becoming convergent toward the cephalic extremity of the optic thalamus, in which structure they take origin or have their destination. The fibers in this limb which occupy the most ventral position pass backward and inward with a slight ascending obliquity in their course. The more dorsal fibers, on the other hand, pass backward, inward and downward; while the intermediate bundles of fibers extend backward and inward in a more horizontal plane. This arrangement results in the formation of a fan-like collection of fibers convergent upon the optic thalamus, into which part of the brain they enter. In their course these fibers come into relation with the head and basal portion of the caudate nucleus, and with the mesial portion of the anterior commissure. They are separated in passing through the capsule into several dissociated groups of fasciculi by the presence of numerous ridges of gray substance which connect the head of the caudate nucleus with the putamen. In the region between the caudate nucleus and the globus pallidus these fibers are crossed by the lenticulo-caudate fasciculi, which arise in the head of the caudate nucleus, pass through the internal capsule to terminate in the globus pallidus and in the lamina medullaris of the lenticular nucleus. The lenticulo-caudate fasciculi are more numerous in the ventral, mesial and caudal portions of the anterior limb.

The *genu of the internal capsule* in the different levels of the thalamic region has a variable constituency. In transverse section through the trunk of the caudate nucleus, the anterior and posterior limbs of the capsule form an obtuse angle in which it is difficult to recognize the actual existence of the genu. Sections on a lower plane through the middle third of the thalamus disclose a genu which consists of horizontal fibers, belonging in reality to the anterior limb. It is only at the level of the ventral portion of the thalamus and the transition from this region to the subthalamus that the genu of the internal capsule is well defined.

The *posterior limb* or *lenticulo-thalamic division of the internal capsule* is formed by vertical and oblique fibers which are convergent toward the basis of the cerebral peduncle. The fibers in this limb of the capsule are present in the thalamic as well as in the subthalamic region. In the thalamic region they pass at first between the body of the caudate nucleus and the dorsal border of the putamen. From this point they descend between the lateral surface of the optic thalamus and the caudo-mesial surface of the lenticular nucleus. The cephalic limit of the posterior limb of the internal capsule is the genu; while its caudal limit is formed by the horizontal fibers of the retro-lenticular division. In the subthalamic region, the posterior limb of the capsule is limited in front by the fibers of the ansa lenticularis,

behind by the lateral geniculate body. Mesially it is in relation with the zona incerta, the fibers of the ansa lenticularis and the corpus Luysi.

According to Déjerine, a number of projection fibers in the posterior limb of the internal capsule terminate in the thalamus. These are cortico-thalamic fibers. Others, cortico-rubral fibers, end in the red nucleus; while some, much fewer in number, terminate in the corpus Luysi and the globus pallidus of the lenticular nucleus. These connections between the cortex and centers at the base of the brain are not admitted by all authorities.

The *retrolenticular division of the internal capsule* is formed by fasciculi which follow a horizontal course forward and inward, passing between the tail of the caudate nucleus and the caudal border of the putamen. These fasciculi are separated by numerous bridges of gray substance which connect the caudal border of the putamen with the tail of the caudate nucleus. The retrolenticular division of the capsule appears in both the thalamic and subthalamic regions, but its fibers do not pass into the basis of the cerebral peduncle. For the most part these fibers are corticopetal, but contained amongst them are some corticofugal fibers.

The principal origin of this division of the internal capsule is in the pulvinar and adjacent parts of the optic thalamus, the lateral geniculate body, and, it may be to a small extent, in the superior colliculus of the midbrain. After emerging from the capsule the fibers come into relation with the cuneus, the fusiform lobule, the precuneus, the angular gyrus and the caudal portion of the parietal and temporal lobes. From this position of the internal capsule the fibers spread out in the optic radiation of Gratiolet.

The *sublenticular division of the internal capsule* is situated ventral to the retrolenticular division. Its dorsal surface is covered by the ventricular ependyma. It is crossed by fibers of the tenia semicircularis and by the curved portion of the tail of the caudate nucleus. Its dorsal surface is in relation with the putamen, the globus pallidus, and in front with the substantia innominata of Reichert. It consists of two distinct fasciculi, namely, the *fasciculus of Türck* and the *fasciculus temporo-thalamicus of Arnold*.

The fasciculus of Türck occupies a caudal position in the sublenticular division of the internal capsule and passes transversely forward and inward along the ventral surface of the putamen, from which point it extends mesially to the lateral aspect of the cerebral peduncle after giving off some fibers to the mesial geniculate body and the ventral portion of the thalamus.

The fasciculus temporo-thalamicus of Arnold occupies a position in the roof and cephalic extremity of the temporal horn of the lateral ventricle. Its fibers are oblique and pass backward and inward. They converge toward the lateral geniculate body and the caudo-ventral portion of the pulvinar, where they unite into a compact bundle.

The fibers in the corona radiata and internal capsule are of two varieties with reference to their length:

1. Short axones which connect the cerebral cortex with the gray matter of the interbrain and midbrain, the cortico-thalamic, cortico-subthalamic

and cortico-mesencephalic fibers. They are referred to collectively as radiations or sometimes spoken of as the peduncles of the several divisions of the gray matter to which they are related. They pass probably in both directions.

2. Long axones which pass into the cerebral peduncle. These fibers serve to connect the pallium of the cerebral hemispheres with the spinal cord, medulla, and pons.

The functional significance of the short and long projection fibers is discussed in the following chapter.

CHAPTER XLIII

THE ENDBRAIN

THE FUNCTIONAL SIGNIFICANCE AND PRINCIPAL SYNDROMES OF THE MEDULLARY SUBSTANCE

THE FUNCTIONAL SIGNIFICANCE OF THE MEDULLARY SUBSTANCE

Functional Significance of the Short Projection Fibers. THE THALAMIC RADIATIONS. The optic thalamus receives a number of projection fibers from the cerebral cortex, the *cortico-thalamic* fibers, and is also connected with the pallium by means of *thalamo-cortical* fibers. These fibers constitute the *thalamic radiations* which are also known as the *thalamic peduncles*. They consist of a series of radiating fasciculi which reach nearly every part of the cerebral pallium. For convenience of description it is desirable to distinguish four principal bundles entering into the thalamic radiations: (1) The anterior peduncle; (2) the middle peduncle; (3) the posterior peduncle, and (4) the inferior peduncle. Each peduncle enters into the corresponding segment of the corona radiata, and also participates in the formation of the internal capsule.

Anterior Thalamic Peduncle. This portion of the thalamic radiation contains fibers which arise or terminate in the lateral, mesial and orbital surfaces of the frontal lobe, in the frontal operculum and in the frontoparietal operculum. They are incorporated in the anterior segment of the corona radiata and in the anterior limb of the internal capsule. They serve to connect the cortex of the frontal lobe with the thalamus, and also to afford a communication between the thalamus and the cortex of this lobe. The connection thus established affects the older portions of the thalamus, namely, the paleothalamus. The thalamo-cortical fibers represent a tract by means of which the impulses entering into the primitive thalamic functions and concerned in the affective reactions of primordial emotion, may become expanded in proportion to the need of the emotional reactions in man. In this manner the stream of primitive emotion and feeling tone spreads into consciousness and commingles with the higher psychic processes represented in the complex experience of the human mind. As a result of this commingling it is probable that every psychic activity of the cerebral cortex is colored to some degree by a feeling tone either of pleasure or displeasure, of attraction or repulsion, arising out of the primitive affective disposition vested in the paleothalamus. The opportunity for an incalculable expansion in consciousness of feeling tone as well as for the correlation of the primitive emotional reactions with the higher psychic faculties, is amply provided for by these thalamo-cortical fibers. The functional significance of the cortico-thalamic fibers, on the other hand, is not so clear. The fibers

entering into this connection form a considerable portion of the anterior peduncle of the thalamus; and it seems fair to presume that they serve some important purpose. From the fact that they may conduct impulses from the frontal region of the cortex to the thalamus, it is probable that these impulses are in some way concerned with the regulation and control of thalamic functions. If permitted to exert their influence without control, the emotional impulses arising in the thalamus would undoubtedly create much confusion in the expression of volitional motion. The sensory combinations entering into primitive feeling tone and the emotive expressions arising out of them, must therefore be subjected to the control of intelligence and experience, or else the complex social adjustments imposed by civilization would not be properly made. For this reason the portion of the cerebral pallium which is directly concerned in the correlation of experience and the constitution of intelligence might well be expected to exert a modifying influence upon primitive emotional reactions. By this means the emotions could be held in check in so far as the proprieties of intelligence might dictate. The cortico-thalamic fibers probably provide the pathway of communication by which the content of the cognitive processes going on in the frontal lobe acquire their affective values from the thalamus. This connection, accordingly, appears not only to subject the primordial feeling tone to the dictates of the will, restraining emotive expression in order to meet the demands of social adjustment, but quite as much reflects upon the thalamus, the psychic activities of the frontal lobe for the purpose of calling into play the proper emotional responses.

This explanation of the significance of the anterior peduncle of the optic thalamus gains in credibility from the fact that in a certain disease, *pseudo-bulbar palsy*, unprovoked attacks of laughing and crying, spasmodic and even convulsive in nature, constitute the most conspicuous symptom. In nearly all cases of this disorder, some lesions, of greater or less extent, exist in the cortico-thalamic and thalamo-cortical fibers, interfering not merely with the opportunities which the cortex affords for the expansion of feeling tone, but also depriving the thalamus of its proper inhibition by means of cortical activity. The patient suffering from this disease laughs spasmodically and is unable to control his laughter, however much he may strive to do so. On the other hand, his laughter is not occasioned by the usual mirth-provoking circumstances; in fact, the feeling tone of the patient is often quite the reverse of the mirth which his laughter seems to express. The extreme degree of risibility manifested by these patients has caused some observers to call this disease the *laughing sickness*. Crying spells of a similar spasmodic nature may replace the laughter, or the two may alternate without corresponding change in the feeling tone of the patient. In view of such evidence as is available, for the present at least, it seems justifiable to presume that the cortico-thalamic and thalamo-cortical fibers provide for the expansion of the primitive feeling tone, and at the same time exercise a control over emotive expression.

The Superior Thalamic Peduncle. This peduncle of the thalamus con-

sists of thalamo-cortical fibers which enter the parietal lobe, particularly the postcentral convolution. They represent a connection between the cortex and the neothalamus, serving as the final link in the somesthetic sensory pathway. From the thalamus, by means of these fibers, impulses concerned in general body sensibility of all qualities pass to the cerebral cortex. According to Head, seven streams concerned in somesthetic sensibility ascend by means of this connection to their primary cortical receiving station in the postcentral area. These seven streams convey tactile and pain impulses, thermal impulses for heat and cold, postural impulses and impulses for two-point recognition and localization upon the surface of the body. Upon reaching the postcentral area of the cortex by means of the thalamo-cortical fibers in the superior thalamic peduncle, the impulses of these seven streams are given opportunity for further expansion and combination in the somestheto-psychic area of the brain. A lesion interrupting this peduncle on its way to the cortex in any portion of its course will produce a complete hemianesthesia on the side of the body opposite the lesion, in which there will be a loss of all the primary qualities of sensibility.

The Posterior Thalamic Peduncle. This peduncle of the thalamus contains the posterior thalamic radiations or the *optic radiation of Gratiolet*. The fibers of this peduncle arise in the caudal extremity of the optic thalamus and in particular in the pulvinar. Some of them also take origin in the lateral geniculate body. They terminate in the upper and lower lips of the calcarine fissure, and some of the fibers extend to the lobulus fusiformis and the third convolution of the occipital lobe. They constitute the mesial layer of the posterior segment of the corona radiata and form the retrolenticular division of the internal capsule. The fibers in this peduncle serve to connect the relay stations of the visual pathway in the pulvinar and lateral geniculate body with the primary receiving centers of vision in the *calcarine or visuo-sensory area*.

The fibers in the posterior peduncle, therefore, serve in a capacity similar to that of the superior peduncle, the latter conveying impulses of general body sensibility, the former conducting visual impulses. An interruption in the optic radiation due to injury or disease results in a homonymous hemianopsia in the visual field of the side opposite the lesion. A clinical feature of this variety of hemianopsia is the fact that the light reflexes are retained as a result of stimulation of the blind retinal fields. This sign is considered indicative of a lesion caudal to the light centers of the midbrain. As the fibers in the posterior thalamic peduncle emerge from the pulvinar and geniculate body, they become collected in a triangular bundle known as the *triangular zone of Wernicke*. This area lies in close proximity to the base of the superior thalamic peduncle, so that the optic and somesthetic radiations may be simultaneously involved by a single pathological process. When such is the case the patient presents a homonymous hemianopsia and a complete hemianesthesia on the side of the body opposite the lesion.

The Inferior Thalamic Peduncle. The fibers in this peduncle connect the thalamus with the temporal lobe. The fibers emerge from the

lateral and ventral surfaces of the thalamus and pass obliquely beneath the ventral surface of the lenticular nucleus. This peduncle serves as the final link in the auditory pathway permitting impulses received by the mesial geniculate body and inferior colliculus to make their ultimate entry into consciousness.

THE RADIATION OF THE SUPERIOR COLLICULUS OF THE MIDBRAIN. The fibers entering into this connection participate in the formation of the optic radiation of Gratiolet. They take origin in the visuo-sensory area, more particularly in the median lips of the calcarine fissure, pass through the corona radiata, the retrolenticular division of the internal capsule, and thence to the tectum of the midbrain in the superior collicular region. These fibers constitute the *visual cortico-collicular fasciculus* and represent an efferent connection between the visuo-sensory cortex and the superior colliculus of the midbrain. It has been suggested, and there seems to be some reason to support the supposition, that the impulses passing from the visual cortex to the colliculus eventually reach the oculomotor, trochlear, abducens and spinal accessory nuclei. Such a pathway from the visuo-sensory cortex to the nuclei of the oculogyric and cephalogyric muscles might be operative in regulating the muscles of the eye and neck in fixation of the gaze. It is true that the attentional fixation of gaze presents two distinctly different types of movement; first, the volitional direction of the eyes toward an object which it is desired to bring into view; and second, the continued fixation of the eyes upon an object already in visual attention despite the movements of the head to the right or left, upward or downward. Thus, when a patient is directed to look out of a window situated upon his extreme right, cephalogyric and oculogyric movements are at once made in that direction in order to bring the window into visual attention. If the examiner clasps the patient's head in his hands and slowly moves the head toward the left instructing the patient to keep his gaze fixed upon the window, the eyes still remain in the position most favorable to retain the object in visual gaze in spite of the movement of the head in the opposite direction. The same test may be applied for objects to the left, above or below. Clinical examples showing the dissociation of these two essential elements of oculogyric and cephalogyric movements have already been cited and seem to warrant the belief that two separate mechanisms may be involved in this operation. The pathway most likely to be concerned in the actual holding of objects in visual attention would naturally have its conscious center in the visual cortex and establish a connection with the oculogyric and cephalogyric centers of the brain-stem. It is probably represented by the visual cortico-tectal radiation.

RADIATION OF THE MESIAL GENICULATE BODY AND INFERIOR COLLICULUS OF THE MIDBRAIN. The connection established by means of this radiation between the inferior colliculus, mesial geniculate and the temporal cortex constitutes the final link between the relay stations in the auditory pathway and the audito-sensory area of the cerebral cortex. The actual termination of these fibers is in the transverse gyri of Heschl. They pass by way of the inferior segment of the corona radiata to the sublenticular division of the

internal capsule. They follow the same general course pursued by the fasciculus of Türk, and coming into relation with the caudal division of the internal capsule, ultimately end in the audito-sensory area of the cortex. The fibers in this radiation, arising in the inferior colliculus, occupy a more ventral position than the fibers arising in the mesial geniculate body. They form a compact bundle, the brachium of the inferior colliculus, which passes in front of the mesial geniculate body and is covered in part of its course by the brachium of the superior colliculus which occupies a more superficial position.

THE RADIATION OF THE NUCLEUS RUBER—RADIATION OF THE RED NUCLEUS. The red nucleus, according to Déjerine, receives fibers from the parietal region of the cerebral cortex. It is probable that this radiation occupies the superior segment of the corona radiata and enters the posterior division of the internal capsule. It passes beneath the radiation of the mesial geniculate body, enters the tegmentum of the midbrain, and ends in the ventro-lateral portion of the red nucleus at its cephalic extremity. Its function appears to be connected with the correlation of cerebral and cerebellar impulses. This radiation may also contain rubro-pallial fibers.

The Functional Significance of the Long Projection Fibers. The long projection fibers establish connection between the cerebral cortex on the one hand and the brain-stem and spinal cord on the other. There are three distinct systems of long projection fibers which may be distinguished with reference to the area of the cortex in which they take origin. These are:

1. The frontal system.
2. The precentral system.
3. The parieto-temporo-occipital system.

THE FRONTAL SYSTEM OF LONG PROJECTION FIBERS. The fibers in this system arise in the frontal lobe especially in relation with the intermediate prefrontal area. They become incorporated in the cephalic segment of the corona radiata, pass mesially and enter the cephalic limb of the internal capsule. They occupy a special compartment caudal to the fibers which form the anterior peduncle of the thalamus. In the subthalamic region of the internal capsule the fibers move into a more caudal position corresponding to the most cephalic portion of the posterior limb, and then enter the mesial compartment of the cerebral peduncle in which they descend to the pons. The fibers terminate in the pontile nuclei, thus forming the *fronto-pontile tract* which is one of the constituents of the fronto-ponto-cerebellar pathway.

This connection serves to bring the cerebral cortex into relation with the cerebellum. It provides for the simultaneous despatch of the motion formula by way of the pyramidal system to the spinal cord and a concurrent series of impulses from the same area of the cortex to the cerebellum, thus activating the synergic units necessary to the performance of skilled acts. It is essential to the proper execution of all volitional movements. By means of this pathway the cerebral cortex and the cerebellar cortex contribute the necessary concurrent influences of volitional and synergic control to the muscles of the body.

THE PRECENTRAL SYSTEM OF LONG PROJECTION FIBERS. These fibers arise in the precentral or Rolandic area. They represent the elements in the cerebral pathway by means of which all volitional impulses are transmitted to the somatic muscles. Arising at different levels in the precentral region, these fibers, which are usually referred to as constituting the *pyramidal system*, pass through the centrum ovale in the superior segment of the corona radiata and enter the genu and posterior limb of the internal capsule. Upon

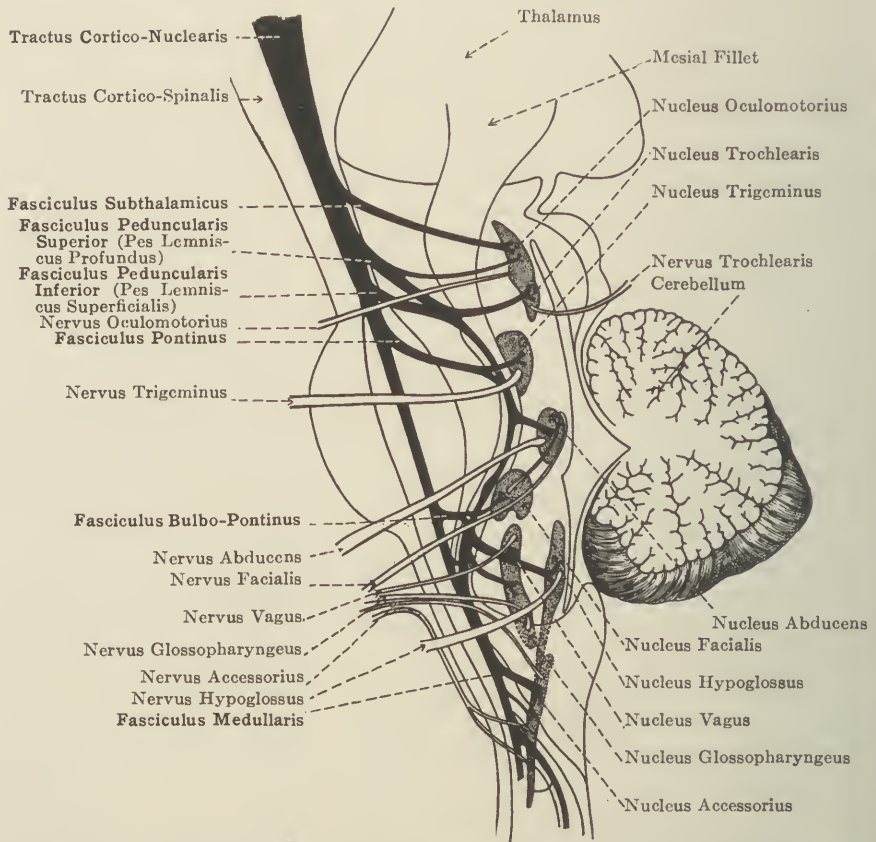


FIG. 504.—The cortico-nuclear pyramidal system; the aberrant pyramidal contingents which in the course of their descent leave the pyramidal tract to pass to the nuclei of the cranial nerves. (Modified from Déjerine.)

coming into relation with this part of the brain, they are topographically disposed in two fasciculi representing subdivisions of the pyramidal system, the *cortico-nuclear contingent* or *aberrant pyramidal system*, and the *cortico-spinal fasciculus* or *pyramidal system proper*.

The Cortico-Nuclear Contingent of the Precentral System. The cortico-nuclear contingent occupies the genu of the internal capsule in the thalamic region, and in the subthalamic region moves progressively caudally through the posterior limb of the capsule until it reaches a compartment in

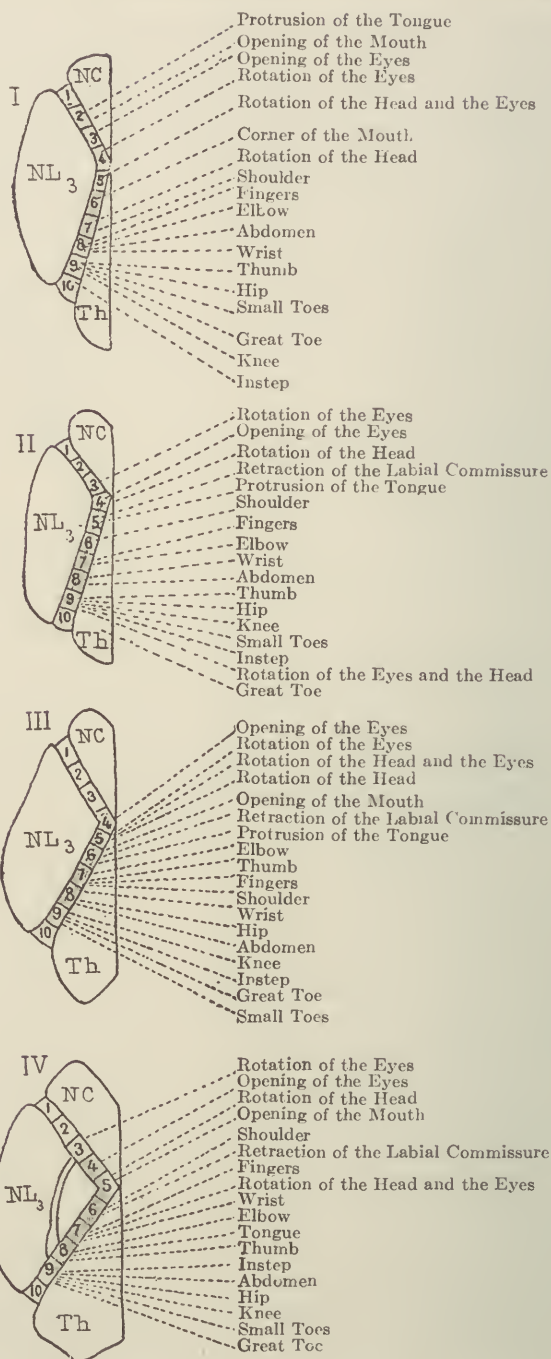
the cerebral peduncle adjacent to the fronto-pontile tract. In the thalamic region of the internal capsule, it is situated immediately caudal to the fronto-pontile tract, and in this position it is susceptible of further subdivision into special fasciculi which serve specialized motor purposes. The most cephalic fasciculus in the cortico-nuclear contingent of the internal capsule comprises fibers which terminate in nuclei controlling the oculomotor apparatus and the neck muscles. This is the *oculogyric and cephalogyric fasciculus*. When it becomes involved the patient suffers from an inability to move the eyes and head in a direction opposite to the lesion. The next succeeding fasciculus in the cortico-nuclear contingent is the *linguo-laryngo-palato-pharyngeal fasciculus*, which supplies volitional impulses to the groups of closely associated muscles in the tongue, palate, pharynx and larynx. The most caudal collection of fibers of the cortico-nuclear contingent of the internal capsule is the *mandibulo-facial fasciculus* which furnishes volitional control to the muscles of mastication and of the face.

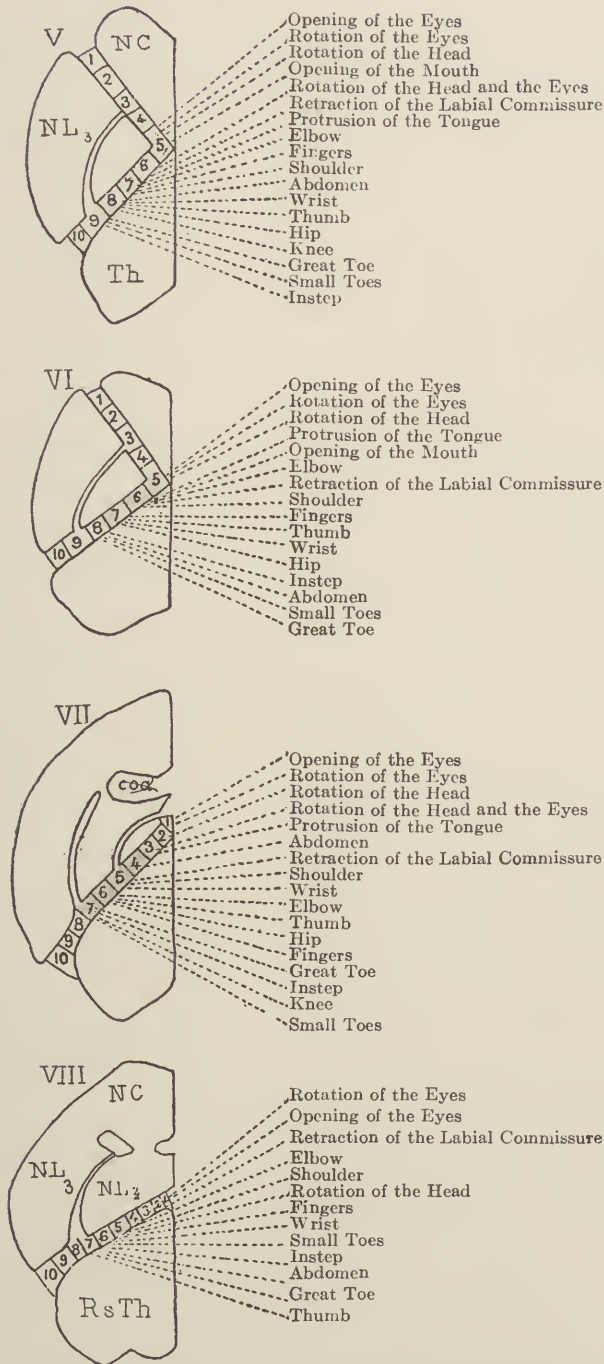
The Cortico-Spinal Contingent of the Precentral System. This collection of fibers in the internal capsule occupies the most cephalic portion of the posterior limb. The collected mass is situated immediately caudal to the genu. The origin of this fasciculus is in that part of the precentral area which gives rise to pyramidal fibers supplying volitional control to the shoulder and arm, trunk, pelvis and leg. The constituent fasciculi entering into this portion of the internal capsule are arranged in such a way that the most cephalic fibers supply voluntary impulses to the shoulder, and in regular succession caudally to the arm, forearm, hand and fingers, trunk, pelvis, thigh, leg, foot and toes.

The two contingent fasciculi which constitute the precentral system of long projection fibers represent the *final common pathway for volitional control* from the cerebral cortex to the ventral gray column of the spinal cord and homologous nuclei in the brain-stem.

THE PARIETO-TEMPORO-OCCIPITAL SYSTEM OF LONG PROJECTION FIBERS. The fibers constituting this system arise in the parietal, temporal and occipital lobes and pass through the posterior segment of the corona radiata to the posterior limb of the internal capsule. From this position they pass into the cerebral peduncle, occupying a position in the lateral portion of the basis pedunculi. The fibers terminate in the pons, where they form a synapsis about the cells of the pontile nuclei, and, like the fronto-pontile tract, establish a parieto-temporo-occipito-pontile tract which proceeds to the cerebellar hemisphere of the opposite side by means of the middle cerebellar peduncle.

The function of the occipital connection is in the interest of adding the function of vision to the process of obtaining synergic control. That vision plays a complementary rôle in this function is observed in cases in which closure of the eyes is attended by a marked increase in asynergic defects. This fact is made use of in the *equilibratory test of Romberg*, and the swaying often developed as a result of closing the eyes is known as *Romberg's sign*.

FIG. 505.—Motor capsular localization in the macacus sinicus. (*Déjerine*.)

FIG. 505.—Motor capsular localization in the macacus sinicus. (*Déjerine*.)

The significance of the temporal connection with the cerebellum is less clearly understood. In all probability, it has a significance similar to that of the visual compensation afforded by the occipital connection. In this case, however, the function of hearing is made use of, to some degree it may be, in equilibratory compensation. On the other hand, it is much more likely that the temporo-pontile cerebellar connection serves in the interest of spatial orientation in relation to the mechanism of the semicircular canals, the utricle and saccule. That such an area actually exists in the cerebral cortex has not been clearly demonstrated, although spatial orientation is a recognized element in consciousness, and equilibratory sensibility must therefore depend upon some cortical representation. For this reason it is probable that the same area which receives the cortical termination of the auditory pathway arising in the eighth nerve may also serve as the end station in consciousness of the other portion of the eighth nerve connected with receptors whose recognized function is spatial orientation. In this light the connection between the temporal portion of the cortex and the cerebellum would have the significance of correlating equilibratory consciousness with the non-conscious activities of the cerebellum in the interests of synergic control.

The parietal element in the parieto-temporo-occipito-pontile tract may be presumed to effect a communication by means of which body-feeling sense, particularly kinesthetic memory, acrognosis and muscle sensibility, are correlated with impulses arising in the cerebellum necessary to synergic control.

Summary of the Arrangement of the Projection Fibers in the Internal Capsule of Man. *The Arrangement of the Projection Fibers in the Thalamic Region of the Internal Capsule.* The anterior limb of the internal capsule contains two fasciculi:

1. The anterior peduncle of the thalamus, which consists of the cortico-thalamic and thalamo-cortical tracts.
2. The fronto-pontile tract.

The genu of the internal capsule contains one fasciculus, the cortico-nuclear contingent of the pyramidal system, which consists of:

1. The cortico-oculogyric tract.
2. The cortico-cephalo-gyric tract.
3. The cortico-vago-glosso-pharyngo-hypoglossal tract.
4. The cortico-trigemino-facial tract.

The posterior limb of the internal capsule contains three fasciculi:

1. The cortico-spinal contingent of the pyramidal system.
2. The superior peduncle of the thalamus, which forms the final connection between the lateral portion of the thalamus and the postcentral area of the cerebral cortex. Some authorities consider that this tract does not exist as a discrete fasciculus of the internal capsule, but is intermingled among the fibers of the pyramidal system. In all probability, however, the fasciculus is discrete and occupies a separate compartment in the capsule.
3. The parieto-temporo-occipito-pontile tract.

The Arrangement of the Projection Fibers in the Subthalamie Region of the Internal Capsule. The anterior limb and genu of the internal capsule have disappeared at this level, due to the confluence of the putamen and the head of the caudate nucleus. The posterior limb alone remains. It contains six fasciculi:

1. The fronto-pontile tract.
2. The cortico-nuclear contingent of the pyramidal system.
3. The cortico-spinal contingent of the pyramidal system.
4. The parieto-temporo-occipito-pontile tract.
5. The posterior peduncle of the thalamus (the optic radiation).
6. The inferior peduncle of the thalamus (the auditory radiation).

The diagrams on pages 786 and 787 show the relative positions of the several constituents of the internal capsule in one of the higher apes.

SYNDROMES DUE TO LESIONS INVOLVING THE INTERNAL CAPSULE

A number of syndromes have been described as the result of lesions involving the internal capsule. It is probable that none of them is entirely pure, since the confines of the capsule are so limited that it seems doubtful that a pathological process could be sufficiently selective to be circumscribed exclusively to any one portion of this region of the brain. There is some clinical advantage, however, in recognizing certain well-defined symptom-complexes which have been identified with lesions in this part of the white matter and serve to make more clear the functional significance of the internal capsule.

Syndrome Due to Unilateral Lesion of the Pyramidal System in the Internal Capsule. This syndrome is probably one of the most common clinical conditions encountered as the result of disease in the brain. It is usually produced by hemorrhage from a small vessel which passes through the internal capsule, known as the *lenticulo-striate artery* or *Charcot's artery of apoplexy*. The lesion limits itself to the genu and first portion of the posterior limb of the capsule, and by producing a block in the flow of impulses from the cortex to the brain-stem and spinal cord, gives rise to the following symptoms:

1. Complete loss of volitional control of the contralateral muscles of the face, tongue, arm, leg and trunk. In some cases the muscles of the pharynx and larynx are also involved, although this latter incidence is relatively rare.

2. The paralysis is of the hypertonic type with marked increase of the deep reflexes. The superficial reflexes are lost. Abnormal associated movements are demonstrable on the affected side. The trunk muscles are much less involved than those of the face and tongue, arm and leg.

3. Somatic sensibility, as well as the special senses, are intact.

This syndrome differs in its nature from the paralysis produced by cortical lesions in the fact of its extensive distribution, which produces a hemiplegic effect, while as a rule cortical and shallow subcortical lesions produce a monoplegia, such as paralysis of the face, tongue, one arm or leg. As a rule, the cortical paralysis is preceded by a period of irritation which causes an

appearance of convulsive movements confined to the side of the body which ultimately becomes paralyzed. These convulsions generally start in some fixed group of muscles such as those of the face, tongue or arm, and gradually spread from this focus of inception until they involve the entire side of the body. Consciousness is not lost during these convulsions, which are known as *Jacksonian* or *focal epilepsy*. Such convulsions are not encountered in the paralysis due to lesions of the internal capsule.

The initial extensive somatic distribution of the paralysis, together with the absence of convulsive seizures, constitutes the distinguishing feature of paralysis due to involvement of the pyramidal system in the internal capsule.

Syndromes Due to Bilateral Lesion in the Cortico-Nuclear Contingent of the Pyramidal System. In a limited number of cases a pathological process has a selective affinity for the portion of the internal capsule on both sides which contains the cortico-nuclear fibers supplying volitional control to the cranial nerve nuclei. When this is the case, the patient presents a complete loss of volitional control over the face, tongue, pharynx and larynx. In rare instances the eye muscles and the muscles of the neck may also suffer. Although volitional control is lost over the movements of the face, tongue, palate, pharynx and larynx, these muscles still remain under reflex control and also present well sustained somatic associated movements. There is no evidence of any loss of idiodynamic control, as the muscles remain in a normal nutritive condition.

The type of facial paralysis under these circumstances is characteristic. The upper, middle and lower portions of the face are paralyzed as far as volitional control is concerned. The facial paralysis in these cases differs from the unilateral involvement of the internal capsule in which event the upper portion of the face still remains under volitional control due to the fact that it is bilaterally innervated from the cortex. The usual type of facial paralysis due to lesion of the internal capsule shows a loss of volitional control of the middle and lower portions of the facial muscles only. In many cases of bilateral cortico-nuclear involvement the lesion is either multiple or more extensive. Some of them involve other systems entering the internal capsule. Quite frequently the anterior peduncle of the thalamus is involved, so that the emotional status undergoes a great change. The patient is subject to spasmodic outbursts of laughter and crying without accompanying circumstances to provoke the emotion. The spasmodic laughter is often so pronounced a feature of this involvement that the disease is sometimes spoken of as the laughing sickness already mentioned.

The cortico-spinal fibers in the capsule are also often involved. This gives rise to a complicating hemiplegia. The syndrome is subject, therefore, to many variations, although its chief feature is a paralysis due to a block in the cortico-nuclear fibers which supply volitional impulses to the motor nuclei of the cranial nerves of both sides. The syndrome is hence referred to as a *supra-nuclear paralysis* or *pseudo-bulbar palsy*. Lesions in other portions of the central axis may give rise to this type of paralysis, such for

example as those found in the pons Varolii or in the tegmentum of the mid-brain; but the association of the spasmodic laughing and crying with an upper motor neurone type of paralysis involving the cranial nerves, is significant of a bilateral lesion involving the internal capsule.

Syndrome of the Carrefour Sensitif of Charcot. Following the teaching of Charcot, it has been held for many years that there occurs a crossing of all the sensory pathways in the internal capsule. In this region the pathways for vision, hearing, body sensibility, taste and smell, pass in close proximity to each other *en route* to their terminations in the cerebral cortex. This sensory crossway was designated by Charcot the *carrefour sensitif*. It was believed that a lesion in the neighborhood of the posterior limb of the internal capsule simultaneously affected all of these sensory pathways. More recent investigation has disproved this theory, although the fibers conveying impulses of body sensibility and vision do lie close together in their passage through the capsule. A lesion involving the posterior limb of the capsule at the junction of its thalamic and subthalamic regions, and particularly that portion which is commonly known as the *triangular field of Wernicke*, will produce complete hemianesthesia on the side of the body opposite the lesion, as well as a homonymous hemianopsia on the side corresponding to the hemianesthesia. This is due to the fact that the optic radiation and superior peduncle of the thalamus which constitutes the final link in the somestheto-sensory pathway, are simultaneously involved by the lesion. In some instances pathologic processes may extend further cephalad affecting the pyramidal system, in which event the hemianesthetic side of the body will present a hemiplegia of the upper motor neurone type. The deep reflexes are increased, pathological reflexes are present, the superficial reflexes disappear, and automatic associated movements are demonstrable.

Syndrome of the Thalamus and Internal Capsule. In certain instances a pathological process simultaneously involves a portion of the thalamus and the internal capsule. In this event the patient presents symptoms attributable to the thalamus and the posterior limb of the capsule. The thalamic symptoms consist of a marked elevation of the affective tone and an instability of the emotions. In addition to presenting a hemianesthesia and hemiplegia on the affected side, the patient manifests a marked hypersensitiveness over the areas in which he is anesthetic. The hemiplegia and hemianesthesia may be complicated by homonymous hemianopsia indicating the involvement of the optic radiation in the retrolenticular portion of the internal capsule. This symptom-complex has been termed the *capsulo-thalamic syndrome*.

THE PROJECTION SYSTEMS OF THE RHINENCEPHALON

The olfactory projection fibers comprise two distinct systems: (1) That connected with the olfactory lobe (the olfactory radiation), the septum pellucidum (the septo-thalamic fasciculus), the fascia dentata and indusium griseum (tenia semicircularis); (2) that connected with the cornu Ammonis and gyrus fornicatus, which constitute the system of the fornix.

establish a connection between these portions of the brain, the ganglion habenulæ and the mesial portion of the optic thalamus.

3. THE TENIA SEMICIRCULARIS. This fasciculus connects the parolfactory area with the nucleus amygdalæ and the optic thalamus. It consists of neurones of the third order in the olfactory tract, and is situated in the thalamo-striate sulcus between the thalamus and the body of the caudate nucleus. It is accompanied by the striate vein.

4. THE PROJECTION SYSTEM OF THE FORNIX. The fibers in this projection system establish connection between the cornu Ammonis, fascia dentata and gyrus fornicatus on the one hand, and the basal regions of the inter-brain, midbrain and subthalamie region on the other. The fornix consists of several parts which include the alveus, the fimbria, the body and the anterior pillar. The fimbria consists of a fasciculus of longitudinal fibers which extend along the mesial border of the cornu Ammonis to enter the lateral border of the posterior pillar of the fornix. The fibers constituting the fimbria arise in the giant cells of the fascia dentata and the cornu Ammonis.

The Alveus. This portion of the fornix system arises in connection with the intraventricular portion of the cornu Ammonis. It presents two divisions, the *intraventricular alveus* and the *extraventricular alveus*. The intraventricular alveus receives fibers from pyramidal cells in the region of the *subiculum of the hippocampus* and from the cornu Ammonis. These fibers ascend in a position more or less parallel to a transverse plane of the hemisphere, then turn forward in a longitudinal plane where they reinforce the fibers of the fimbria. The extraventricular portion of the alveus consists of fibers which arise in the polymorphous cells in the fascia dentata. These fibers constitute the lesser portion of the alveus and pass in a longitudinal direction to join the fimbria. The fimbria, extraventricular alveus and intraventricular alveus may be followed forward as far as the body of the fornix of which they form a part. The fimbria occupies the lateral portion of the fasciculus which ultimately enters into the posterior pillar of the fornix. The extraventricular alveus occupies the mesial portion of this fasciculus, while the intraventricular alveus is situated between these two bundles.

The Posterior Pillar of the Fornix. This structure consists of a large fasciculus which passes in an arch inward, upward and forward. Its dorsal aspect comes into relation with the ventral surface of the corpus callosum and contains in this portion the intraventricular portion of the alveus and certain perforating fibers which penetrate the splenium and caudal extremity of the body of the corpus callosum. Its ventral portion contains the fibers of the fimbria and gradually becomes attenuated to a thin border which affords attachment to the chorioid plexus. The posterior pillar of the fornix makes a sharp flexure beneath the lateral portion of the splenium of the corpus callosum, and gradually approaches the corresponding structure of the opposite side to form the body of the fornix. The commissural fibers in connection with the posterior pillar of the fornix are known as the transverse commissural fibers constituting the *lyre of David*—

psalterium Davidi. The greater portion of the axones of the posterior pillar are continued forward in a sagittal direction into the body of the fornix. They are the direct continuation of the fibers of the fimbria and both divisions of the alveus.

The Body of the Fornix. This structure appears as a large fasciculus somewhat flattened and triangular form, situated beneath the corpus callosum. A deep median sulcus separates the corresponding halves of the

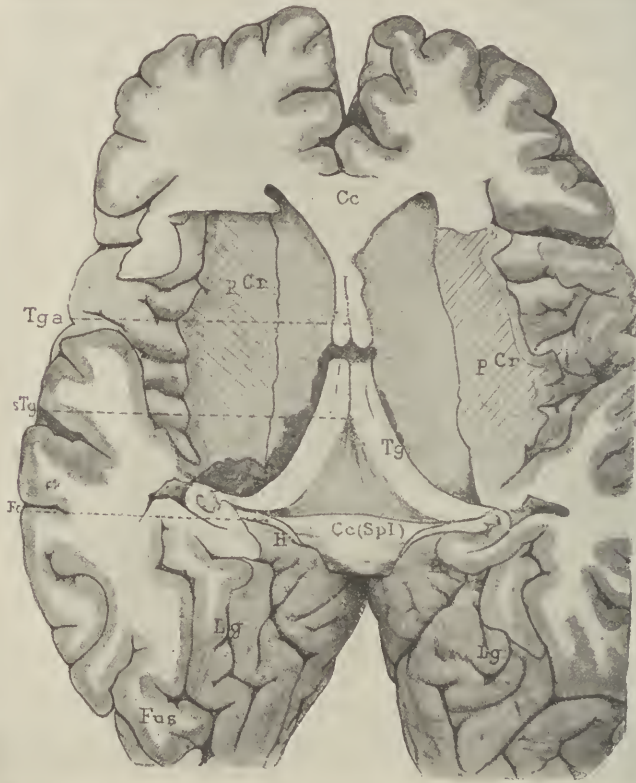


FIG. 507.—The inferior surface of the body of the fornix and of the splenium of the corpus callosum. (From a photograph of a brain hardened in formalin.) (Déjerine.)

Gc—Genu of the corpus callosum; *Cc (Spl)*—splenium of the corpus callosum; *Fc*—fasciola cinerea; *Fus*—fusiform lobule; *H*—hippocampal convolution; *Lg*—lingual lobule; *pCr*—foot of the corona radiata; *Tg*—body of the fornix; *sTg*—the median fissure of the inferior surface; *Tga*—the anterior pillar of the fornix. The triangular space between the two halves of the body of the fornix and the splenium of the corpus callosum correspond to the lyre of David, separated from the inferior surface of the trunk of the corpus callosum by the narrow neuroglial lamina between the two fornices.

two sides which are connected by means of a thin layer of neuroglial tissue, the *lamina fornicis*. The body of the fornix contains a continuation of the fibers of the fimbria, the intraventricular alveus and the extraventricular alveus. The fibers of the intraventricular alveus occupy a meso-lateral position, those of the fimbria are situated ventro-laterally, while the extraventricular alveus is mesial in its position. The fimbria, together with the intra- and extraventricular alveus, consists of fibers which take origin in

the hippocampal convolution and in the cornu Ammonis. These fibers are further reinforced by many others which perforate the corpus callosum in its several portions. Prior to this perforation the fibers which are contained in the striæ Lancisii arise in the indusium griseum. The perforating fornix fibers, therefore, represent extra-hippocampal axones which arise in parts of the limbic lobe outside of the hippocampal gyrus. Several groups of these perforating fibers may be distinguished. The caudal perforating fibers pass

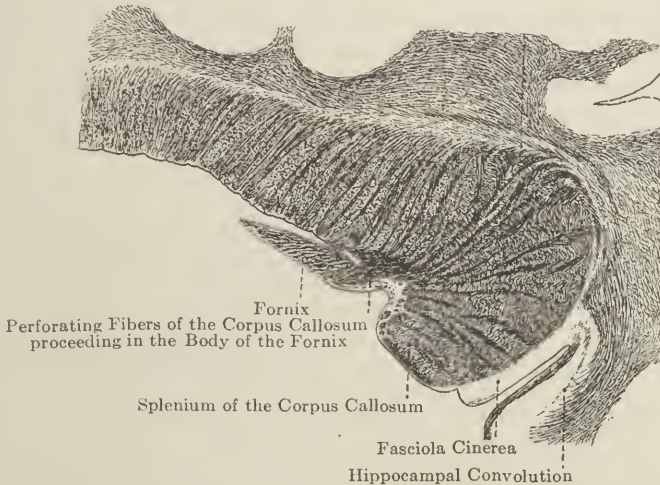


FIG. 508.—The perforating fibers of the splenium of the corpus callosum, seen on sagittal section. Method of Weigert-Pal. (*Déjerine*.)

through the splenium and the caudal one-third of the body of the corpus callosum. The middle perforating fibers penetrate the middle third and run forward in the ventral border of the septum pellucidum of which they form the peduncle. The cephalic perforating fibers penetrate the genu and rostrum and pass into the septum pellucidum, constituting a part of its peduncle. Some of these fibers take origin in the cingulum. From the anterior third of the body of the corpus callosum a large number of fibers detach themselves from the concavity of the body of the fornix and pass into the septum pellucidum forming the olfactory fasciculus of the fornix. This bundle of fibers constitutes a large association fasciculus connecting the cornu Ammonis, the gyrus dentatus, the gyrus fasciolaris, the striæ Lancisii, the gyrus fornicatus and the septum pellucidum with each other. It also establishes connection with the anterior perforated space and the tuberculum olfactorium. The fibers which perforate the *corpus callosum* constitute the *fornix longus*.

The Anterior Pillars of the Fornix. At a level immediately cephalad of the derivation of the olfactory fasciculus, the body of the fornix diminishes in size and becomes rounded in shape. At this point the chorioid plexus of the lateral ventricle is attached to its meso-ventral border and is continuous with the median chorioid plexus of the third ventricle. The fimbria ceases to

form a distinct fasciculus and is fused intimately with the fibers of the alveus and the fornix longus. The rounded bundle formed in this manner constitutes the anterior pillar of the fornix, which passes forward upon either side, becomes slightly divergent, and then turns downward and inward. It passes behind the anterior commissure, submerges itself in the central gray substance in the supra-optic region and the tuber cinereum, finally terminating in the mammillary body. In the supra-optic region the anterior pillar of the fornix passes above the optic chiasm and the anterior commissure, mesial to the genu of the internal capsule and the anterior portion of the optic thalamus. The majority of the fibers of the anterior pillar of the fornix terminate in the lateral nucleus of the mammillary body. This connection constitutes the first link in the efferent pathway of the rhinencephalon by means of which impulses arising in the olfactory cortex make their way toward the

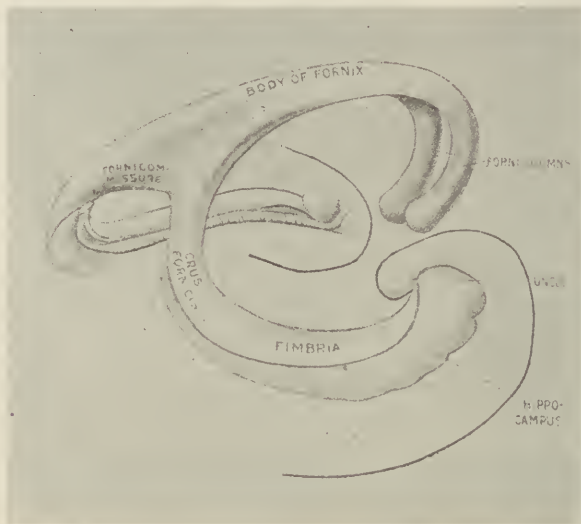


FIG. 509.—Diagram of the fornix. (*Gray.*)

several executive organs of the body. From the mammillary body by way of the fasciculus of Vicq-d'Azyr, the impulses are carried upwards to the anterior nucleus of the thalamus and backwards finally to reach the habenular ganglion, from which point they are conducted by the *fasciculus retroflexus* of Meynert to the *interpeduncular ganglion* of Ganser. The next tract in the efferent olfactory pathway is the peduncle of this interpeduncular ganglion which connects it with the *dorsal tegmentum ganglion* of Gudden in the midbrain. This latter nucleus serves as the origin of the *fasciculus longitudinalis dorsalis* of Shütze, which is an ancient motor pathway establishing communication between the rhinencephalon on the one hand and the brain-stem and spinal cord on the other.

Functional Significance of the Projection Systems Entering into the Rhinencephalon. The projection fibers of the olfactory lobe and septum

pellucidum, which include both the superficial and the deep olfactory radiations, the septo-thalamic fasciculus and the tenia semicircularis, constitute afferent pathways from the end-organs of the olfactory receptors to the central parts of the nervous system in which olfactory sensibility is elaborated. The projection system of the fornix constitutes the efferent projection system from the rhinencephalon and the olfactory cortex by way of the mammillary bodies, the anterior nucleus of the thalamus, the ganglion habenulæ, the interpeduncular ganglion and the dorsal tegmental ganglion of Gudden, in the interests of establishing a motor pathway to respond to olfactory stimulation. These two systems, the afferent olfactory projection system on the one hand, and the efferent olfactory system on the other, complete a reflex arc by means of which olfactory impulses received by the olfactory receptors can be transmitted, interpreted and transformed into motor impulses capable of producing responses in the somatic effectors necessary for procuring food.

CHAPTER XLIV

THE ENDBRAIN

THE INTERNAL NUCLEI OF THE CEREBRAL HEMISPHERES

The Internal Nuclei or the Basal Ganglia. Situated in the medullary substance of each hemisphere and almost completely separated from the cortex, is a group of nuclei, collectively known as the basal ganglia. These ganglia include: (1) The caudate and lenticular nuclei, which constitute the corpus striatum; (2) the claustrum, and (3) the amygdaloid nucleus.

THE CORPUS STRIATUM. The corpus striatum is situated near the base of each hemisphere, lateral to the optic thalamus. It consists of a large, ovoid mass of gray matter, imbedded in the white substance. In large part it is extraventricular, although a portion of it is visible in the frontal horn of the lateral ventricle. The name, corpus striatum, has been applied to this part of the brain in consequence of certain striations caused by the presence of laminae of white matter. The striate body is penetrated by the fibers of the internal capsule which constitutes the largest of these laminae. Several other strips of medullary substance still further subdivide the corpus striatum and form the boundaries between its component parts.

The Lenticular Nucleus. The more lateral of the two portions of the corpus striatum is the lenticular nucleus. It has a generally biconcave or wedge-shaped outline. Its greatest length is 5 cm.; in width it is 3 cm., and in thickness 2 cm. It is almost entirely surrounded by the medullary substance of the hemisphere, and presents a caudo-mesial, a cephalo-mesial, a lateral and a ventral surface. The ventral surface is continuous laterally with the head of the caudate nucleus. The lateral surface of the nucleus is co-extensive with the inner aspect of the island of Reil and its greatest width is opposite the cephalic limit of the thalamus. Its appearance on coronal section is triangular. The caudo-mesial surface of the striate body is in relation with the lateral aspect of the posterior limb of the internal capsule. The cephalo-mesial surface borders upon the lateral aspect of the anterior limb of the capsule. The lateral surface is slightly convex and is in relation with the external capsule. The ventral surface is continuous with the basal surface of the hemisphere.

Two white lines, the laminae medullares, extending in general parallel with the lateral surface, subdivide the lenticular nucleus into three zones. The outermost zone is the *putamen*, which is the largest, darkish red in color, and is penetrated by many transverse radiate striæ. The innermost portion of the lenticular nucleus is the *globus pallidus* which is separated from the putamen by the *lamina medullaris externa*. The globus pallidus in the recent state has a yellowish or brownish appearance. It is divided into two portions

by the *lamina medullaris interna*, a mesial portion, limb I, and a lateral portion, limb II.

It is of much importance from the standpoint of development and evolution to note certain fundamental differences which characterize the lenticular nucleus. The globus pallidus in its two limbs presents an appearance of striking similarity; while the putamen, even in the gross, has marked differences which distinguish it from the more mesial portion of the nucleus. This differentiation between the putamen and the globus pallidus takes its significance from the fact that the globus pallidus is primordial, while the putamen is a late acquisition. The distinction between these two parts of

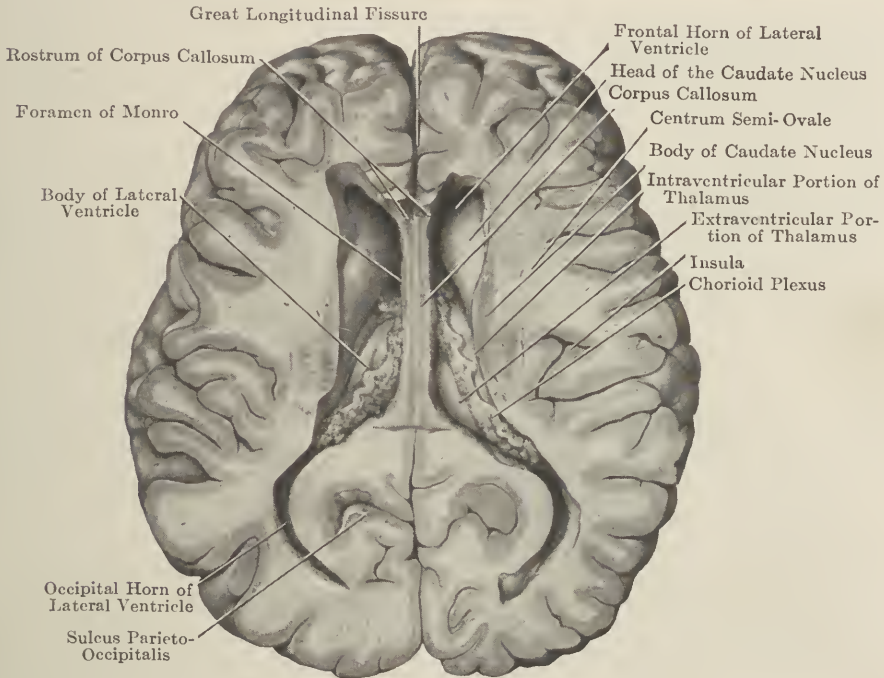


FIG. 510.—Horizontal section of the cerebral hemispheres ventral to the corpus callosum.

the lenticular nucleus becomes still more clear in the light of their internal structure.

The Caudate Nucleus—Nucleus Caudatus. The caudate nucleus is the more mesial portion of the corpus striatum and is in part intraventricular. A portion of it appears in the frontal horn of the lateral ventricle of which it forms the ventro-lateral wall, while a portion of the nucleus is in relation with the body and temporal horn of the lateral ventricle. In form the caudate nucleus is comet-shaped, having a large head, a long, curved, slender body, and a long, curved tail. The parts of the caudate nucleus are therefore: (1) The head (*caput nuclei caudati*); (2) the body (*corpus nuclei caudati*); (3) the tail (*cauda nuclei caudati*). The entire nucleus measures 6.5 to 7.0 cm. in length and 1.5 to 2.0 cm. in width. The head of the nucleus

is much the largest of its three parts, and occupies an intraventricular position. On coronal section the head is ovoid in outline. Its mesial surface protrudes into the frontal horn of the lateral ventricle and is covered by the ependyma of this cavity. Its lateral surface is in contact with the lenticulo-caudate segment of the internal capsule. The internal capsule separates this surface of the caudate nucleus from the ventro-mesial surface of the lenticular nucleus. The ventral border of the caudate nucleus is continuous with the putamen of the lenticular nucleus. This confluence occurs in the region below the anterior limb of the internal capsule; in other words, in the area in which the fibers of the capsule have been deflected

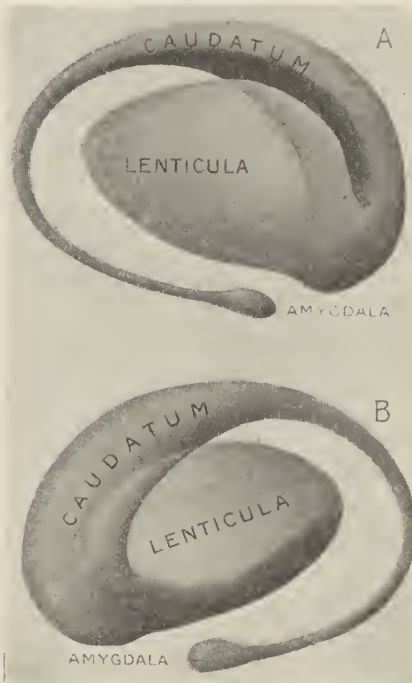


FIG. 511.—Two views of a model of the striatum: A, lateral view aspect; B, mesial view. (Gray.)

caudally and are beginning to assume that portion of their course in which they enter the cerebral peduncle. The fusion between the head of the caudate nucleus and the putamen of the lenticular nucleus in the basal region of the hemisphere is apparent on coronal section. This is the portion of the basal ganglia in which separation has never occurred. The invasion of the projection fibers of the internal capsule seeking a means of exit from or entrance into the hemisphere, has produced the marked separation which occurs between the head of the caudate nucleus and the lenticular nucleus.

The cephalic pole of the caudate nucleus extends forward into the medullary substance of the frontal lobe, and the head itself is co-extensive with the frontal horn of the lateral ventricle. The caudal pole of the head of the caudate nucleus is situated in relation with the cephalic extremity of the optic thalamus. At

this point the nucleus caudatus becomes greatly attenuated. From the dorsal aspect of its head there extends a slender body which passes along the dorso-lateral border of the optic thalamus. These two structures together form the floor of the body of the lateral ventricle. At the caudal extremity of the dorsal surface of the thalamus the body of the caudate nucleus undergoes still further attenuation and, as the tail of this nucleus, sweeps around the caudal aspect of the optic thalamus to enter the roof of the temporal horn of the lateral ventricle. It passes as far forward as the tip of the temporal lobe and ends in connection with the nucleus amygdalæ.

The corpus striatum consists, therefore, of the lenticular and caudate

nuclei. The lenticular nucleus contains the ancient part or *paleostriatum*, the globus pallidus, which is divided by the internal medullary lamina into limb I and limb II. A more modern portion of the striate body, the *neostriatum*, comprises the putamen and caudate nucleus. The caudate nucleus consists of a head, a body and a curved tail. The head is connected by a massive bridge of gray matter with the cephalic extremity of the putamen in the basal region of the frontal lobe. This constitutes the internuclear bridge of the corpus striatum. Several lesser strands of gray matter bridge the gap between the head of the caudate nucleus and the lenticular nucleus in the region of the anterior limb of the internal capsule. These are the accessory internuclear bridges.

Both the principal and accessory bridges are due to the fact that the projection fibers forming the internal capsule have either left the mass of the corpus striatum entirely unaffected, or have incompletely produced a separation as a result of their invasion.

The intraventricular portion of the body and tail of the caudate nucleus is covered by the ventricular ependyma.

INTERNAL STRUCTURE AND HISTOLOGY OF THE CORPUS STRIATUM. The corpus striatum contains four types of cells:

1. The small nerve-cells, measuring 8 to 10 micra in diameter, and having a more or less spherical or polygonal outline. Their protoplasm is scant and their staining reaction feeble.

2. Medium-sized cells, containing a few chromophilic granules.

3. Giant cells, which are generally stellate in shape and contain a nucleus of considerable size and a cytoplasm filled with masses of chromophilic substance.

4. Neurogliform cells.

Small and Medium-Sized Cells with Short Axones. Small cells are numerous in the head, body and tail of the caudate nucleus and in the putamen of the lenticular nucleus. The axones in some cases arise from the body of the cell and in others from the base of one of its dendrites. They break up into a profuse arborization, the end branches of which are either varicose or free.

Medium-sized cells with short axones are found in the caudate nucleus and the putamen of the lenticular nucleus. They are also present but less numerous in the globus pallidus. Their axones, which usually arise from the body of the cell, are very delicate and either serve as association fibers within this portion of the corpus striatum, or else pass from the putamen of the lenticular nucleus to the globus pallidus.

Large Pyramidal or Ganglionic Cells. These cellular elements are of large size, measuring in diameter from 40 to 50 micra. They have long protoplasmic processes with moderate arborizations. They are pyramidal, fusiform and triangular in shape. Their axones give off a number of collaterals and enter into the formation of the fasciculi constituting the projection fibers of the corpus striatum. These cells are also known as the *giant cells of the corpus striatum*. They are found mostly in the globus pallidus and only



FIG. 512.—Horizontal section through the brain.

a few of them are present in the putamen of the lenticular nucleus and the head of the caudate nucleus. They constitute the chief cellular elements in the two limbs of the globus pallidus. It is by means of the collected mass of their efferent fibers that connections between the corpus striatum and the brain-stem are established.

Dwarf Cells or Neurogliform Cells. These cells are small, varying from 6 to 10 micra in diameter. They are spherical in form and on first glance have the appearance of neuroglial cells. They, however, are possessed of dendrites which arborize profusely, and a short and slender axone which breaks up into a profuse arborization. These cells are for the most part found in the head of the caudate nucleus and the putamen of the lenticular nucleus.

DISTRIBUTION OF THE SEVERAL TYPES OF CELLS IN THE CORPUS STRIATUM. The globus pallidus consists of a single type of cell, namely, the large pyramidal or giant cells, which are multipolar and of the stichochrome type. This fact associates them with the motor variety of neurone. Because the chief cellular element in this portion of the corpus striatum is the large multipolar cells, the globus pallidus is referred to as an *isomorphic portion* (having but one structural element) of the striate body. In contrast to the globus pallidus, the putamen and caudate nucleus are composed principally of two distinct types of cells. The more numerous of these are the small, pyramidal, stellate or polygonal cells which give the characteristic histological distinction to these parts of the striate body. Among the smaller cells are scattered some cellular elements of larger size. The large cells are multipolar, contain Nissl granules, and often have a deposit of yellow pigment. They resemble the larger cells of the globus pallidus, and may be regarded as identical in structure with them. From the fact that the putamen and the caudate nucleus consist of two cell types, they are referred to as the *allomorphic portion* (having several structural elements) of the striate body. The large pyramidal or giant cells in the globus pallidus, as well as in the putamen, measure 70 micra in length by 10 to 15 micra in width. The smaller cells are about

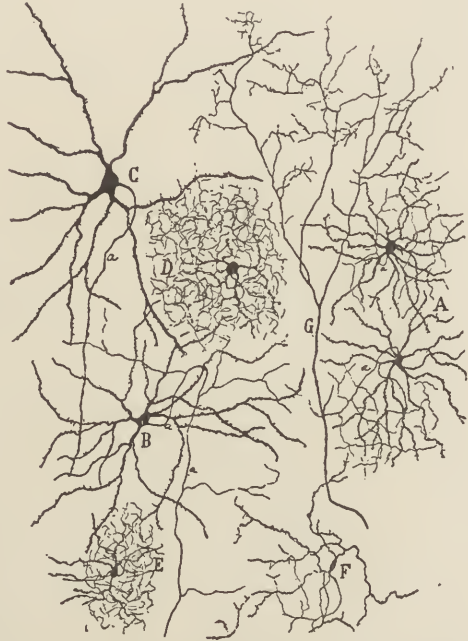


FIG. 513.—Several cellular types from the striate nucleus in the region near the claustrum; brain of a child. Golgi's method. (Cajal.)

A—Cells with small trunks having short axis cylinders. B—Cell with long descending axis cylinder. C—Giant cell with long axis cylinder. D, E—Dwarf cells with short axis cylinders. G—Ramifying ascending fiber. a—Axis cylinder.

one-third the size of these large elements. The large pyramidal cells in the globus pallidus possess a long axis cylinder derived from the base of the cell. They present long and thick apical dendrites and several lateral dendritic processes. The smaller cells have a short axis cylinder and several small dendritic processes. The long axis cylinders from the cells of the globus pallidus make their way from this part of the brain by the ansa lenticularis into the thalamic and subthalamic regions. The small cells represent an internuclear system of association fibers uniting the caudate nucleus with the putamen, and these two in turn with the globus pallidus. Large cells of the globus pallidus constitute a short projection system which unites the corpus striatum with the important nuclei of the thalamic region.

Malone has been able to identify characteristics in the cells of the globus pallidus distinctive of the motor type of neurone. The globus pallidus may be regarded, therefore, as a part of the motor mechanism of the brain. The putamen and caudate nucleus represent a later acquisition which in all probability exerts some influence upon the activities of the more primordial portion of the corpus striatum without directly contributing to the control of the final common pathway.

The General Significance of the Corpus Striatum. The corpus striatum in mammals is regarded as the homologue of the basal forebrain ganglion in lower vertebrates. This ganglion forms a considerable portion of the prosencephalon. It gives rise to a voluminous bundle of fibers, the *basal forebrain bundle* (*fasciculus basilaris*). The cells of the ganglion are very numerous in fish, reptiles and birds, but are relatively few in amphibia. The cells of the nucleus in fish are ovoid in form as is also the case in amphibia. They give rise to protoplasmic trunks which terminate in a profuse end arborization, while from the opposite pole the axone arises to take part in the formation of the basal fasciculus. In reptiles, the cells in this ganglion are of large size and their axones are long. The shape of the cell is stellate. The axones enter into the basal fasciculus. In birds, the cells are also large and the long axones from them become part of the basal fasciculus. Smaller cells, however, give rise to short axones which also become incorporated in the basal fasciculus. Thus, in the lower vertebrates, the morphological prototypes of the two major varieties of cells seen in the mammals are already apparent; that is, the large giant cells and the medium-sized cells. The basal fasciculus is a system of fibers in fish, amphibians, reptiles and birds which appears to be the homologue of the motor pathway in man. It occupies, in the lowest forms, a basal position, passes backward through the interbrain, midbrain and hindbrain to enter the spinal cord. In all probability it contains afferent and efferent fibers, those of the ascending variety being sensory and those of the descending, motor. The basal fasciculus contains short fibers which terminate in the anterior nucleus of the optic thalamus and also in the lateral geniculate body. It also includes long fibers which descend as far as the cord. These are the motor fibers which arise in the forebrain and constitute the septo-mesencephalic fasciculus which is probably the homologue of the pyramidal tract in mammals. In animals possessing no cerebral

cortex, such as the fish, there is but a single motor pathway connecting the higher parts of the central nervous system with the lower segmented portions, the basal fasciculus. When, however, the cortex becomes differentiated, a new cortical motor center is created above the primordial one in the basal ganglion. This new motor center develops a new motor pathway. As a result of this new order the somatic muscles come under a dual control; first, that dependent upon the primitive connection between the corpus striatum and the segmented portions of the neuraxis, which because of its ancient character may be called the *paleokinetic motor pathway*; and second, the connection established by means of fibers arising in the cerebral cortex, which because of its subsequent acquisition in the process of evolution may be termed the *neokinetic motor pathway*.

In its process of evolution from the lower vertebrates to mammals, the primordial portion of the striate body corresponds to the globus pallidus. This structure may, therefore, be tentatively distinguished as the *paleostriatum*. The basal forebrain ganglion of the fish is regarded as the forerunner of the paleostriatum. When, however, amphibious life was first established, newer parts were added to the corpus striatum with the purpose of further extending the correlation of motor impulses. These later acquired portions of the striate body constitute the *neostriatum*, which is present for the first time in reptiles. It gradually increases in size and prominence in birds and mammals. In mammals, the neostriatum is further subdivided by the presence of the massive system of projection fibers of the internal capsule. These fibers penetrate the corpus striatum in such a way as to separate the caudate from the lenticular nucleus. The putamen of the lenticular nucleus and the nucleus caudatus constitute the neostriatum. The phylogenetic distinction between the old and new portions of the corpus striatum is important as indicating the gradual extension in the correlation of motor impulses which took place in passing from the lower to the higher vertebrates. This distinction is further emphasized by the histological appearances in the paleostriatum which consists almost exclusively of motor cells, while the neostriatum contains chiefly smaller cells giving rise to internuncial fibers. The fact that the paleostriatum is found in lower vertebrates while the neostriatum first makes its appearance in the reptiles seems to indicate a momentous modification in motor activity. This change in all probability corresponds to the epoch in evolution when the transition from aquatic to terrestrial life became thoroughly established and new conditions of the environment imposed the necessity of special motor adaptations on land.

Connections of the Corpus Striatum. The fibers which enter into the formation of the corpus striatum are of three varieties:

1. Projection fibers constituting the radiations of the corpus striatum.
2. The internuclear fibers.
3. The penetrating fibers or *fibers of passage*.

THE PROJECTION FIBERS. RADIATIONS OF THE CORPUS STRIATUM. By means of its radiations, the corpus striatum is connected with the interbrain and the midbrain by a system of fibers which have much significance

in the interpretation of the functions of this part of the nervous system. These fibers appear as an important part of the ground plan of the brain of all vertebrates. Primordially, the connection between the corpus striatum, the midbrain and interbrain, is established by the *basal bundle of the prosencephalon*, which constitutes the chief projection system of the striate body. This bundle comprises the *strio-thalamic*, *strio-subthalamic* and *strio-mesencephalic radiations*. It serves to connect the corpus striatum with the optic thalamus, the subthalamic region, the corpus Luysi, the red nucleus and the substantia nigra.

The Strio-Thalamic Radiation. This fasciculus emerges from the mesial surface of the globus pallidus. It traverses the posterior limb of the internal capsule to the middle and inferior portions of the thalamic region and radiates into the ventral portion of the thalamus. There are also thalamo-striate fibers in this radiation.

The Strio-Subthalamic Radiation. This system of fibers constitutes the most complex and extensive radiation of the striate body. The fibers emerge from the mesial surface of the lenticular nucleus and finally become concentrated in a single layer between the globus pallidus and the posterior limb of the internal capsule. They are disposed in three more or less distinct groups; a dorsal group which passes inwards above the corpus Luysi, forming the *lenticular fasciculus of Forel*; a median group which terminates in the corpus Luysi, forming the *Luysien fasciculus* or *fasciculus strio-subthalamicus*, and a ventral group which passes into the cephalic extremity of the subthalamic region forming the *ansa lenticularis*. These three groups of fibers collectively have been designated by von Monakow the *ansa of the lenticular nucleus*, in which a dorsal, median and ventral division may be recognized. These divisions correspond with the three groups of fibers in the striatal radiations previously mentioned.

The Lenticular Fasciculus of Forel. (Dorsal division in the ansa of the lenticular nucleus of von Monakow.) This fasciculus connects the corpus striatum with the ventro-cephalic portion of the thalamus. Its fibers radiate from the globus pallidus and pass in numerous fasciculi through the anterior two-thirds of the posterior limb of the internal capsule. Here they become assembled to form a large, flat fasciculus above and in front of the corpus subthalamicum. The fasciculus then proceeds inward in close relation to the thalamic fasciculus of Forel. It gives off some fibers to the central gray matter of the third ventricle, to the fields of Forel, to the dorso-cephalic portion of the capsule surrounding the red nucleus, and finally radiates into the ventro-cephalic portion of the thalamus. This fasciculus constitutes the main group of the ansa lenticularis and establishes a definite connection of much physiological importance between the globus pallidus and red nucleus. Its fibers may easily be distinguished from those of the internal capsule, as well as from any other tract in the neighborhood.

The Fasciculus Strio-Subthalamicus or Luysien Fasciculus. (Median division in the ansa of the lenticular nucleus of von Monakow.) This fasciculus forms a series of radiations which in general follow a course below

and a little behind the fibers constituting the lenticular fasciculus of Forel. Its fibers traverse the anterior two-thirds of the posterior segment of the internal capsule. They penetrate and for the most part terminate in the corpus subthalamicum. This fasciculus is composed of finely myelinated fibers arising in the radial bundles of the globus pallidus. Some fibers cross the body of Luys and make their way to the neighborhood of the lateral portion of the capsule of the red nucleus. A small number of these fine fibers also pass obliquely across the crus cerebri in a mesial direction ventral to the corpus subthalamicum to terminate in the region of the substantia nigra.

The Ansa Lenticularis. (Ventral division in the ansa of the lenticular nucleus of von Monakow.) This fasciculus consists of a large bundle situated below and in front of the radiation forming the strio-subthalamic fasciculus. The fibers arise in the globus pallidus and are supplemented by a certain number coming from the lamina medullaris interna. In contradistinction to the lenticular fasciculus of Forel and the fasciculus strio-subthalamicus, the ansa lenticularis does not pass by a direct and short path through the posterior limb of the internal capsule, but turns sharply downward to run in a horizontal direction inward, slightly in front of the posterior capsular limb. In this part of its course it extends along the ventral surface of the lenticular nucleus and appears in the *substantia innominata sublenticularis* of Reichert. Here it passes almost at right angles to fibers of the internal capsule and follows a course parallel to the optic tract above which it is situated. With the ventral peduncle of the thalamus it forms the *ansa peduncularis* of Gratiolet already described. The two principal fasciculi of the ansa peduncularis are separated from one another by a thin layer of gray matter containing a large number of nerve cells, the *ganglion of the ansa peduncularis*. After reaching the subthalamic region some of the fibers in the ansa lenticularis pass upward into the ventro-cephalic portion of the thalamus, where they terminate in common with the fibers of the lenticular fasciculus of Forel. Some fibers from this bundle take a much longer course in the direction of the ganglion habenulæ, while others extend backward, giving off collaterals to the central gray matter of the third ventricle, finally penetrating into the meso-cephalic portion of the capsule surrounding the red nucleus.

The Strio-Mesencephalic Radiation. There is some evidence that certain fibers arising in the striate body terminate in the midbrain. The exact termination of this striatal radiation has not been definitely determined, although some authorities believe that the fibers end in the substantia nigra. The axones establishing this connection appear as finely myelinated fibers incorporated in the fasciculus strio-thalamicus. Their function is not understood.

Origin of the Striatal Projection Fibers. The projection fibers of the corpus striatum arise, in the main, from the large or giant cells of the globus pallidus and terminate in the ventro-cephalic portion of the thalamus, the corpus subthalamicum, the central gray matter of the third ven-

tricle, the red nucleus, and probably the substantia nigra. In addition to these fibers which arise in the corpus striatum (striofugal fibers) there are others which take origin elsewhere and end in the striate body. Among these striopetal axones are thalamo-striate and subthalamo-striate fibers. Several bundles of axones which arise in the thalamus establish connection with this part of the brain and the caudate nucleus. According to Déjerine, a number of subthalamo-striate fibers may be traced from the subthalamic region into the ansa lenticularis and lenticular fasciculus of Forel. It would appear, therefore, that while the ansa lenticularis and the strio-subthalamic fasciculi are, to a very large extent, striofugal, they also contain some striopetal fibers.

INTERNUCLEAR FIBERS OF THE CORPUS STRIATUM. The internuclear group of fibers take origin in the small cells of the caudate nucleus and the putamen. They make their way to and terminate in the lateral and mesial segments of the globus pallidus. These fibers form the delicate medullary pencils which radiate through the putamen (the *radial fascicles of the putamen*), and to some extent are seen in the head of the caudate nucleus (the *radial fascicles of the nucleus caudatus*). They constitute one of the characteristic histological features of this part of the brain. According to some authorities the internuclear fibers, in small numbers at least, pass across the internal capsule into the striæ thalamicæ to the lateral margin of the thalamus. This, however, has been questioned, and it seems probable that all of the internuclear fibers in the corpus striatum limit themselves in origin and destination to the striate body.

The internuclear fibers from the putamen to the globus pallidus are variable in number and in calibre. Usually they are fine, myelinated axones. They are massed in small bundles or pencils.

Other internuclear fibers extend from the caudate nucleus to the putamen. These are fibers which cross the dorsal third of the posterior limb of the internal capsule.

The Laminæ Medullares. The lateral lamina is composed in great part of caudate association fibers passing in both directions. Some of the globus pallidus and putamen fibers enter into its constitution for a short distance. The mesial lamina is composed of short connecting fibers passing both dorsally and ventrally. These are mainly internuclear fibers between the lateral and mesial zones of the globus pallidus.

PENETRATING FIBERS AND POSSIBLE CONNECTIONS OF THE CORPUS STRIATUM WITH THE CEREBRAL CORTEX. Experimental as well as clinical evidence fails to establish any direct connection between the cerebral cortex on the one hand and the caudate nucleus and putamen of the lenticular nucleus on the other. Some collaterals from the projection system of the cerebral cortex make their way into the corpus striatum from the internal capsule, but these are fine and few in number. The existence of direct cortico-striate fibers is still to be demonstrated. There is some evidence indicating that a small connection exists between the cerebral cortex and the globus pallidus and corpus of Luys. The globus pallidus receives at its caudal

extremity through the laminae medullares some fibers from the cortex. These fibers enter the gray substance of the corpus striatum. In a similar manner, the thalamus and corpus Luysi also receive cortical fibers which thus establish indirect connections between the cerebral cortex and striate body.

Apart from penetrating thalamo-cortical fibers crossing the corpus striatum, there are no connections between the lenticular nucleus and the cortex. These thalamo-cortical axones are *fibers of passage* which make their way through the corpus striatum without establishing direct connections with it. They are insignificant in number and pass out of the lateral surface of the putamen.

The Claustrum. This structure is a thin layer of gray substance imbedded in the white matter between the lateral surface of the putamen and the cortex of the island of Reil. The mesial surface of the claustrum is smooth and parallel with the outer surface of the putamen from which it is separated by a thin band of white matter, the *external capsule*. It is separated from the mesial surface of the insula by the *capsula extrema*. On transverse section the claustrum is attenuated in front and behind. It is regarded by some authorities as a distinct portion of the corpus striatum. By other investigators the claustrum is considered to be a detached inner layer of the cortex. Its nerve cells are, for the most part, small and either stellate or fusiform in shape. Its connections are not understood and its function is still to be ascertained.

The Nucleus Amygdalæ—Amygdaloid Nucleus. This structure also known as the *archistriatum*, is a mass of gray matter of considerable size situated near the pole of the temporal lobe. It lies in close proximity to the uncus and overlies the cephalic extremity of the temporal horn of the lateral ventricle. It is continuous with the cortical gray matter of the temporal lobe at its cephalic extremity. Its caudal portion receives the tail of the caudate nucleus and the tenia semicircularis. The nucleus comes into close relation with the anterior perforated space.

CHAPTER XLV

THE ENDBRAIN

FUNCTIONAL SIGNIFICANCE AND PRINCIPAL SYNDROMES OF THE CORPUS STRIATUM

Experimental Investigation. The views of those who have studied the corpus striatum vary considerably concerning its function. The older investigators encountered difficulties in differentiating between the function of the caudate and the lenticular nuclei. The caudate nucleus was more accessible to approach and hence the earlier research dealt particularly with it. The more important opinions concerning the functions of the corpus striatum are helpful in understanding the problems involved in this region of the brain.

Among the earliest investigators of the corpus striatum, Willis and Vieussens considered this portion of the brain as the center of common sensibility (*sensorium commune*). This view was sustained by many clinicians who regarded the corpus striatum as a structure which by its sensory activities controlled and regulated volitional movement. The theory that the striate body was essentially sensory in its function early began to lose ground, and although this claim has been made in even later times, the corpus striatum by general acceptance is now regarded, as an organ whose functions are fundamentally motor. The motor character of the striate body was first suggested by Serres and Foville. Majendie as a result of mechanical stimulation of the caudate nucleus by means of a needle, came to the conclusion that the movements in the forward direction of locomotion were under the influence of the cerebellum, while those in the backward direction were controlled by the corpus striatum. If this latter body were destroyed, the animal could run forward owing to the uncontrolled action of the cerebellum. Longet did not agree with the theory of Willis concerning the sensory nature of the corpus striatum, and as a result of his experiments upon rabbits, in which he first removed the cerebral hemispheres and then the corpora striata, was unable to give assent to the correctness of Majendie's conclusion concerning the influence of the corpus striatum upon locomotor movements backward. On the other hand, Majendie's views were subsequently supported by Schiff, Beaunis, Fournié, Lausanna, LeMoigne and Nothnagel. Fournié, by means of injecting chloride of zinc into the caudate nucleus in dogs, produced strong progression movements, and considered the corpus striatum a center for the regulation of voluntary movements. Beaunis, by means of injections of sodium hydrate, also obtained forced movements in rabbits. Nothnagel by means of a syringe injected minute quantities of pure chromic acid into the caudate nucleus.

In this ganglion, he discerned a structure which when stimulated produce violent forward movements in rabbits, for which reason he called the caudate nucleus the *nodus cursorius*. Flechsig, as early as 1870, stimulated the lenticular nucleus by a special electrical instrument and produced powerful contractions of the contralateral muscles of the body. Ferrier concluded that irritation of the corpus striatum caused a general muscular contraction of the opposite side of the body. The head and body were strongly flexed to the opposite side, the facial muscles being in a state of tonic contraction and the limbs maintained in a flexed position. Nothnagel regarded the corpus striatum as entirely a center for synthesized unconscious habitual movements. Luciani and Tamburini believed the caudate nucleus a part of the mechanism controlling the motor acts which are phyletically ancient. Prus, by means of electric stimulation, observed tono-clonic spasms and running movements in experimental animals. He concluded that the corpus striatum influenced the tonic status of the muscles. Opinion, however, has been somewhat divided concerning the motor function of the corpus striatum. Its excitability by various means of stimulation has been questioned. Baginsky and Lehmann regarded the nucleus caudatus as an integral portion of the motor region of the brain. Munk came to the conclusion that the corpus striatum is concerned with habitual somatic movements. Johansen as a result of his experiments upon dogs, produced tonic cramps by stimulation of the lenticular nucleus, and came to the conclusion that this organ bore some relation to the genesis of convulsions. Bechterew, although he regarded the putamen and caudate nucleus as different in their function from the globus pallidus, maintained that the lenticular nucleus in its mesial portion was part of the motor system. In his opinion the globus pallidus gives rise to a special tract of extra-pyramidal fibers, stimulation of which produces movements of the opposite side of the body. The putamen he associated with the caudate nucleus, presumably denying to it any function of a motor character. Wilson, as a result of experiments upon apes (*macacus rhesus* and *macacus sinicus*) by means of the stereotaxic instrument of Clarke and Horsley, came to the conclusion that the corpus striatum acted as a steadying mechanism upon the pyramidal system and that through its extra-pyramidal connection it effected a stability in the actions of the voluntary muscles.

Although the experiments of a number of investigators give negative or contrary results, the opinion of the majority of authorities is perhaps best expressed in the words of Bechterew to the effect that the lenticular nucleus is to be considered as a formation in which is located the reflex automatic center, and that the corpus striatum as a whole belongs definitely to the motor system.

Phyletic Significance of the Corpus Striatum. In order to obtain an adequate conception of the corpus striatum it is necessary to consider its significance in connection with its relations to the several classes of vertebrates. The striate body is a primordial structure in the vertebrate brain. In the lowest form (the fish), it represents the highest center for the correla-

tion of motor impulses. It receives from the thalamus and also, to some extent, from the midbrain sensory stimuli which it proceeds to transform into motor impulses. This is the case in animals whose motor activities are limited to relatively simple and fixed reactions. In the fish, somatic motion is represented principally by the swimming movements of the body and fins. These movements are characterized by two prominent features: (1) their constant rhythmical continuation, and (2) their intimate and apparently automatic association. The swimming movements of the fish must be constant whether the animal is in motion or merely maintaining itself in some position in the water. A continuous but variable rhythm is also observed, and such variations as occur are instituted by changes in the requirements of locomotion and station. The movements are associated in that one body segment cooperates with all the others in a definite undulatory movement which is dependent upon intersegmental participation of the several body segments. These movements appear to be automatic, because they require no period of individual effort for their acquisition. They are transmitted directly from parents to offspring as motion formulæ ready for immediate use in the locomotion of the fish. They are in this sense phylogenetically conditioned, and represent the organization of an inherent motor mechanism sufficient to the limited motor requirements of the animal.

The essential features of these primitive automatic associated movements are: (1) Their constancy; (2) Their rhythm; (3) their intersegmental association, and (4) the automatic nature in which they accomplish a definite purpose. All these features may be observed in the constant swimming movements of the fish, which involve intersegmental body movements and the correspondingly rhythmical movements of the fins. The assumption of terrestrial life, however, necessitated and determined a marked change. The constancy of the movements which is indispensable to the fish becomes distinctly disadvantageous upon the assumption of life on land. The unremitting motor activity is unnecessary to the purposes of the terrestrial animal. It is needless dissipation of motor energy. For this reason the paleostriatum which controls these primitive automatic associated movements, required some influence to check the incessancy of its action. This tendency to check the constant automatic associated movements resulted in the development of an important inhibitory element.

It is evident what would occur in the case of reptiles, for example, if the constant undulating movements characteristic of the fish should persist on land. The incessant movement would be an unnecessary expenditure of energy. It would also tend to injury of the covering of the body. This marked difference in the motor activity of fish and reptiles furnishes one of the distinguishing features between these animals. Constant, rhythmical, undulatory movements of the body and fins provide the fish with the ability to maintain its place in the water. Inconstant, undulatory movements of the body, subject to long intervals of complete inhibition, characterize the motor mechanism of the reptile. In the epoch when reptilian forms made their appearance, the corpus striatum developed an accessory, the neostri-

atum. It seems probable that this new portion of the striate body introduced the elements of inhibition which held in check the constancy of movement mediated through the activity of the paleostriatum.

But even with this relatively large addition to the striate body in reptiles, the endbrain did not suffice to make adequate provision for all the needed adaptation which was subsequently to develop. The corpus striatum in consequence passed through still further expansion. New demands were made upon it to meet the motor specialization occasioned by the development of wings. These expansions made possible the combinations of automatic associated acts seen in the flying movements of birds. These automatic associations consist of the synchronous oscillation of the wings, adduction and extension of the legs beneath the tail, as well as the fixed position of the tail itself in flight. From birds to mammals, a still further expansion in the combination of automatic associated acts has occurred.

Automatic Associated Acts in Man. An excellent example of automatic associated movements is seen in the horse or dog while running or walking. The movements of the hind and fore legs are synchronized in such way that they afford the most power in progression and the greatest security in maintaining an equilibrated position. A remarkable number of automatic associated acts are found in man. They depend upon the cooperation of many correlated groups of muscles which give rise to a series of combined and associated movements necessary to the accomplishment of a definite purpose. Three types of these movements may be distinguished in man: 1, axio-appendicular; 2, axial; 3, appendicular associated movements.

AXIO-APPENDICULAR AUTOMATIC ASSOCIATED MOVEMENTS. The best known in man are the synchronous movements of the arm and leg in walking and running. While walking, the arms are swung forward and backward in definite time with the gait, the right arm swinging forward with the left leg, the left arm with the right leg. This synchronous and rhythmical alternation of arms and legs undoubtedly harks back to the automatic associated movements in the running act of the quadruped. The automatic associated character of the movements of the arms and legs is further emphasized by the actions of a runner during a race. The runner exerts his strength to increase his speed by the synchronous movements of the arms with the legs.

Another variety of automatic associated movements of the axio-appendicular type is seen in the arms and legs in turning to the right or left, also in rising and sitting down, jumping, falling and climbing. Perhaps no action illustrates better the complex automatic associations than the attitudes and movements executed in striking a blow. This act automatically provides the combinations of muscular contractions necessary to primitive performances of aggression and defense.

AXIAL AUTOMATIC ASSOCIATED MOVEMENTS. These movements are well represented by the muscular cooperation which takes place in the muscles of the neck and trunk in standing, walking or running, and thus determines certain associated positions of the head and body. Other axial automatic

associated acts are seen in the facial musculature, in the bilateral participation of portions of the facial muscles in emotional expression, in the movement of the eyelids in conjunction with those of the eyeballs, and the associated movements produced by the ocular, facial, cervical and truncal muscles in looking upward or downward, to the right or to the left.

APPENDICULAR AUTOMATIC ASSOCIATED MOVEMENTS. Many movements of this type are seen in the upper and lower extremities. On movements of the toes in man, all the toes are, as a rule, moved simultaneously in flexion or extension. Very little, if any, individualized control has been gained over the foot. In flexion and extension, both the toes and the foot move at the same time. In the upper extremities the association of the finger movements in opening and closing the entire hand is shown by the general tendency of flexion and extension to involve the muscles controlling all of the fingers. This automatic association of the toes and fingers is undoubtedly referable to the poorly differentiated movements of the lower animals represented by associated digital activities of the paws.

Another automatic movement of the hand is observed in the tendency to flex the wrist when the fingers are extended, and the simultaneous extension of the wrist upon flexing the fingers.

These examples are but a few of the much larger number of similar motor activities belonging to this category. They suffice, however, to demonstrate the fact that an appreciable number of automatic associated movements have been and still are fundamental parts in the motor endowment of the vertebrate stock.

The functions of the corpus striatum appear to be the regulation of certain automatic associated movements as well as a definite control over the tone of the striated muscles of the body. This ancient and primordial regulation of muscular activity had its inception in the lowest vertebrates and has persisted in its essential characters throughout the entire vertebrate line. It represents a part of the motor organization which, because of its archeal character, may be termed the *paleokinetic system*.

Relation of the Motor Cortex to the Corpus Striatum. The corpus striatum contributes its influence to the final common pathway by means of its connection with the red nucleus through striatal radiations. These fibers establish a striato-rubro-spinal pathway and thus make possible the introduction of the motor influences of the corpus striatum into the control of the somatic muscles. The striate body in itself did not possess a potentiality of development sufficient to meet the demands of the greatly expanded motor sphere. In consequence of its limitation, there developed in connection with the most expansible portion of the brain, the cerebral pallium, a region known as the motor area. By means of this new motor equipment a great variety of activities was made possible. This new type of motor regulation over the somatic muscles not only added the element of volitional control, but also increased the inhibitory influences regulating the muscular tissue. Volitional control of this type was capable of producing activities more effective than those arising in the more primitive paleokinetic system.

In fact, this newer motor mechanism, which may be called the *neokinetic system*, almost from the first began to take precedence over the older system. Volitional control by the motor cortex became progressive, while the automatic associated control of the corpus striatum made little advance and even seemed to be recessive. Automatic associated movements, although not suppressed or submerged, were distinctly overshadowed by the great range of volitional acts which were acquired by the individual and which represented the latest attainments of the mammalian motor organization. The neokinetic system had its inception with the earliest of the mammals and from this time gradually increased its dominance over the paleokinetic system. Under certain circumstances the dominance of the neokinetic system becomes defective, and then the more ancient motor regulation reasserts itself. This is the case in man when as a result of natal or prenatal disease or injury, the motor area of the cerebral pallium fails to develop on one side. The infant thus affected soon presents a voluntary paralysis of one side of the body. In the course of time the paralyzed limbs, especially the arms, manifest a more or less constant rhythmical movement called *athetosis*. This seldom occurs in adults suffering from an interruption in the neokinetic control; such patients as these more usually present one or more of the following abnormal automatic associated movements which indicate that the primitive motor control has reasserted itself.

Abnormal Associated Movements of Clinical Importance. Certain automatic associated movements make their appearance under abnormal conditions, especially when there is an interruption in the neokinetic system which permits the paleokinetic system to reassert its influence. These phenomena are regarded as valuable clinical signs indicating a lesion somewhere in the pallio-spinal connection. Several of the more important of these signs are:

THE HEMIPLEGIC ARM SIGN. This sign, indicative of exaggerated automatic movements, is observed in the arm of many hemiplegic patients when walking. As the patient walks the paralyzed arm is abducted from the body, flexed at the elbow, and swung in a forced manner in consonance with the sound leg.

THE STRETCHING SIGN. Many hemiplegic patients upon awaking in the morning will yawn and stretch both arms, even lifting the paralyzed arm well above the head. They get the impression from this motion that the power has returned to the paralyzed muscles. As soon as the stretching is over, however, the voluntary paralysis reasserts itself and the paralyzed arm is as useless as before. This automatic associated movement accompanying yawning is also known as the *pandiculation (stretching) sign*.

THE RADIALIS SIGN OF STRÜMPPELL. This sign is an exaggeration of a normal automatic associated movement, and consists of an inability to close the fist without marked dorsal extension of the hand.

THE LEG SIGN OF NERI. When the patient, in a standing position, bends the body forward, the paralyzed leg flexes at the knee while the other leg remains extended.

THE TRUNK-THIGH SIGN OF BABINSKI. In this abnormal automatic associated act, the patient when lying recumbent with arms folded across the chest, shows a much greater elevation of the paralyzed leg when he attempts to assume the sitting position.

THE RE-ENFORCEMENT SIGN OF BABINSKI. In this abnormal associated movement the patient while sitting with the legs hanging free is instructed to grasp both hands firmly and then attempt to pull them apart. During the performance of this act extension of the paralyzed leg occurs.

THE TIBIALIS SIGN OF STRÜMPPELL. This abnormal associated act occurs when the patient, in the recumbent position, flexes the leg on the thigh against resistance. Under these conditions there appear simultaneous extension and inversion of the paralyzed foot.

THE TOE EXTENSION SIGN OF BABINSKI. This abnormal associated act occurs when the patient is in a recumbent position and flexes the leg and thigh sharply with the result that a marked extension of the big toe is produced.

THE COUGHING SIGN OF HUNTINGTON. This abnormal associated movement is developed when the patient is recumbent with his legs hanging over the edge of the table. Upon coughing, flexion of the thigh and extension of the paralyzed leg are produced.

Spontaneous abnormal associated movements, such as athetosis, are occasioned by lesions affecting some part of the paleokinetic system and are most frequently the result of lesions involving the corpus striatum.

THE PRINCIPAL SYNDROMES OF THE CORPUS STRIATUM

The more recent clinical work upon the striate body indicates that at least three fairly distinct syndromes may be ascribed to lesions in this part of the brain. It is possible that the delineation of the symptoms included in each of these syndromes is somewhat more discrete than further investigation of this region will justify. On the other hand, an understanding of the syndromes themselves cannot fail to be of assistance in the proper appreciation of these parts of the brain. The most pronounced symptoms entering into the three striatal syndromes are: changes in muscle tone; the appearance of a peculiar type of tremor; the development of certain choreiform and athetoid movements; and the suppression or marked alteration in the performance of normal automatic associated movements.

The Syndrome of the Globus Pallidus. **HISTORY.** The patient was a young woman thirty-nine years of age, unmarried. Her previous history revealed nothing of importance. The malady from which she suffered began when she was about nineteen years of age. The first symptom was the sensation of a cramp in the right foot. It was not constant, and only appeared when she was tired or toward the end of the day when the muscles felt stiff and rigid. In the morning on awakening the cramp had disappeared. This symptom continued for some time and gradually increased in severity and constancy so that eventually the evening cramp became

permanent. For several years the disability was limited to stiffness and weakness of the right foot and leg, but when she was twenty-three years old the right hand began to tremble. The tremor of the hand came on gradually and was not constant. It appeared at a certain times only and then, without apparent reason, it disappeared. Little by little it became a fixture, so that in time there was present a constant marked trembling which increased as the disease progressed. In her thirtieth year the first evidence of a similar trouble appeared on the left side; here there was stiffness on moving the leg. This was followed by tremor of the hand and arm similar in all respects to that affecting the right side. The trouble was at first hemisomatic in type and remained so for three years, when it became general. It is important to note that the disease began at the early age of nineteen and steadily progressed from that time; her chief symptoms were stiffness and weakness in the limbs, difficulty in walking and tremor in the arms and head.

EXAMINATION. At the time the examination was made the patient was in her thirty-ninth year. She appeared upon inspection to be fairly well nourished. Neurological examination made at this time revealed the following facts:

The *somatic motor component* showed that the idiodynamic control was well preserved in all muscle groups, there being no loss in volume or contour of any of the muscles. The tonic control, on the other hand, showed marked change. The muscles of the neck presented a definite tendency to rigidity, and the facial muscles showed some slight fixity of expression. The arm, forearm and hand groups of muscles showed a similar



FIG. 514.—A case of juvenile paralysis agitans. Syndrome of the globus pallidus. (Hunt.)

increase in tone. On passive movement there was a distinct rhythmical interruption, so-called *cog-wheel symptom*, due to the increased myotonus. This same condition of increased tone was observed in the trunk and the lower extremities. The activity of the deep reflexes was normal on both sides as was also the case with the superficial reflexes; no pathological reflexes were observed at any time. Automatic associated control showed a marked defect. There was a distinct suppression of the normal automatic associated movements; in walking there was a lack of normal synchronism of the movements of the arm, trunk, leg and neck muscles; on sitting down and rising from the sitting posture this same defect was observed, while the normal automatic associated movements in facial expression, especially in the expression of emotion, showed a distinct loss on the two sides of the face. The attitude in standing showed the body slightly bent forward and the arms held at the side, a posture usually recognized as the *Parkinsonian attitude*. Synergic control, in so far as it was possible to test the movements necessary to perform the finger-to-nose and heel-to-knee tests, showed no departure from the normal other than that which might be attributed to the unusual stiffness and slowness of muscular movement. Volitional control of the muscles still remained in nearly normal condition, and had it not been for the presence of a coarse tremor in the muscles of the upper extremities and neck, and the undue slowness in the performance of all skilled acts, volitional control might have been regarded as normal. The slowness and the tremor, however, produced a marked defect which cannot be placed in the group of paralyses. The tremor consisted of four to five vibrations a second. It was coarser in the right than in the left hand, where it had a greater amplitude. When the hands were relaxed the tremor manifested itself in the fingers. During the performance of some volitional acts the tremor tended to disappear, while on increased exertion or emotional excitement it made its reappearance.

The *somatic sensory component* was normal.

The *splanchnic motor component* as well as the *splanchnic sensory component* showed nothing abnormal.

INTERPRETATION AND ANATOMICAL ANALYSIS. The lesion in this case was due to a progressive degenerative process. The localizing evidence indicates some site in the nervous system which gives rise to extra-pyramidal symptoms, including increase in myotonus, suppression of automatic associated movements, tremor and a reduction in the celerity of volitional movements. A lesion in the globus pallidus of the lenticular nucleus would give rise to all the symptoms observed in the case.

The evidence of circumscription of the lesion is afforded by the absence of all signs of other somatic symptoms, such as marked volitional paralysis, increase of the deep reflexes, loss of the superficial reflexes, and the appearance of pathological reflexes. The absence of somatic sensory and splanchnic symptoms further serves to limit the lesion to the area of the globus pallidus.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this condition is *progressive bilateral degeneration in the globus pallidus*.

NOMENCLATURE. This is known as the *syndrome of the globus pallidus*, *juvenile paralysis agitans* or the *paleo-striatal syndrome of Ramsay Hunt*.

SUMMARY. The essential clinical features of juvenile paralysis agitans are:

1. The development of the disease in early life.
2. The development of increased muscle tone throughout the entire body, with the development of the characteristic attitude and facies of paralysis agitans.
3. Suppression of the normal automatic associated movements.
4. The appearance of tremor characterized by its occurrence during rest but increased by exertion or emotional excitement.
5. The absence of all pyramidal signs.
6. The absence of all somatic sensory and splanchnic disturbances.

The Syndrome of the Lenticular Nucleus (*Putamen*). HISTORY. A boy fifteen years of age noticed a change in his power to control the right hand. When he attempted to write or button his clothes the fingers of the right hand and the forearm trembled. If excited, he found that both hands shook in a stiff and rigid manner. In the course of four months not only his right arm grew stiffer, but at the same time a stiffness made its appearance in the entire body musculature so that his neck and back became rigid, the muscles of his face were tense and drawn, and apparently a similar condition existed in his tongue. The muscular rigidity brought on certain mal-attitudes in his legs and arms. He would lie on one side or the other with his thighs flexed upon his pelvis, his legs flexed upon his thighs, with his feet in plantar flexion and inversion. His arms were also held in a contracture-like attitude, the left arm was internally rotated, the forearm extended on the arm, the wrist flexed upon the forearm, and the fingers, particularly the index finger and thumb, flexed at the proximal joints. The right arm was internally rotated in slight adduction. The forearm was flexed upon the arm and the wrist and fingers were also flexed. In this hypertonic condition of the musculature it became impossible for the patient to maintain a sitting posture, since the slightest disturbance of his equilibrium would cause him to fall backwards if not supported. In falling, his limbs would retain the original attitude assumed before he began to fall, so that his whole body seemed to move as a single piece. In standing, the stiffness of the muscles was apparent. The tremor, which was one of the earliest signs of his trouble, spread to all the muscles of the right upper extremity and then to the left side. It had a constant rate and rhythm, although during motion of the arm its amplitude as well as its force increased considerably. In this respect it showed a notable difference from the tremor of paralysis agitans. In spite of the marked hypertonicity of the muscles and the increased tremor of the upper extremities, there was a remarkable degree of voluntary control over the muscles and no real paralysis of the parts could be detected. The patient could move his arms and legs at will, and his efforts in these respects gave the impression of a voluntary exertion laboring in the performance of an act against the resistance of his muscular rigidity. In the course of several

months he began to experience some difficulty in swallowing and his speech became still more difficult to understand. From time to time he would give voice to a peculiar cry which did not seem particularly expressive of pleasure or pain, nor did it have any apparent provocation in his surroundings. His intellectual faculties remained keen. His facial expression was suggestive of imbecility, but a moment's conversation with the patient showed that his mind was normally alert.



FIG. 515.



FIG. 516.

FIGS. 515 AND 516.—A case of Wilson's disease. Progressive lenticular degeneration

Fifteen months from the onset of the disease he began to run an irregularly rising temperature, became much emaciated, suffered from profuse sweats and gave all the appearance of a severe toxemia, as the result of which he died after several weeks. The disease was progressive from the time of the onset.

EXAMINATION. At the time of his examination four months prior to death he appeared to be a well nourished boy, rather small for his years.

His glandular status showed that the thyroid, thymus, lymph glands and spleen were normal.

The *somatic motor component* showed that the idiodynamic control was normal in all parts of the body. The reflex control manifested no changes in the superficial or deep reflexes, all of which were active and equal on the two sides. No pathological reflexes, such as the Babinski, were observed at any time during the illness. The tonic control of the muscles, on the other hand, revealed a marked departure from the normal in that there was pronounced hypertonus affecting the entire musculature of the face, neck, trunk, arms and legs. This was sufficient to produce mal-attitudes in the extremities and body.

Automatic associated control was seriously defective. This was apparently due to the fact that the muscles were themselves so rigid that any type of motor response found difficulty in expressing itself. A tremor was present in both upper extremities and to some extent in the legs. This tremor was increased by action and only seldom appeared during rest. It was also increased by emotion. Volitional control was secondarily impaired due to the marked rigidity of the muscles, although no paralysis in the strict sense was present. The gait, because of the muscular rigidity, grew progressively more defective. The patient, however, could move both legs and arms at will. Skilled acts could be performed, although there was a definite interference with the control of all volitional motions occasioned by the stiffness of the muscles. The patient suffered from no loss of internal speech, but there was a pronounced dysarthria which was attributed to the hypertonus of the muscles of the jaw, lips, tongue and pharynx. The muscle strength was apparently normal and under the control of the will. The electrical reactions were normal. Synergic and equilibratory control could not be satisfactorily tested because of the marked interference with volitional control due to the stiffness of the muscles. The motor cranial nerves showed no palsies. There was no paralysis on either side of the face although the facial muscles were rigid and gave the mouth a gaping appearance. There was no paralysis of the hypoglossal nerve, though the intrinsic muscles of the tongue were hypertonic.

The *somatic sensory component* was normal with the exception of an occasional painful cramp in the extremities. All qualities of somesthetic sensibility were normal, including touch, temperature, vibratory, pressure, muscle-tendon and pain. There was no astereognosis and no baragnosis.

The *splanchnic motor and sensory components* showed no departure from the normal except in the later stages of the disease, when a marked vasomotor instability developed as a result of the profound toxemia.

The laboratory findings and X-rays in the case were negative.

INTERPRETATION AND ANATOMICAL ANALYSIS. In this case there was a rapidly progressive degenerative lesion. Evidence of the focus of the lesion is furnished by the definite involvement of the extra-pyramidal system originating in the corpus striatum. Such symptoms might be produced by a lesion in the lenticular nucleus. The more marked degree of hypertonus of

the muscles, together with the appearance of the tremor during action rather than at rest, would suggest the involvement of the inhibitory portion of the corpus striatum rather than the more primitive paleostriatum.

Evidence of circumscription of the lesion is afforded by the absence of all signs referable to the pyramidal system as well as the absence of somatic sensory and splanchnic symptoms.

DIAGNOSIS AND PATHOLOGY. The diagnosis of this case is *progressive bilateral lenticular degeneration* involving the putamen. With this condition in the brain there is invariably found a hypertrophic cirrhosis of the liver which is a *sine qua non* of the syndrome.

NOMENCLATURE. This disease is known as the *syndrome of Wilson (Wilson's disease)*. It is also called the *syndrome of progressive lenticular degeneration* (especially affecting the putamen).

VARIATIONS. Clinically there are two types of this disease, the acute or sub-acute form and the chronic form. The two types differ very little from each other except in the rapidity with which the invariably fatal termination is reached. The acute cases are apt to have some febrile disturbances from the beginning and the duration is usually from 4 to 15 months. The chronic cases may last from 1 to 4 years after the appearance of the first symptoms.

SUMMARY. The essential clinical features of the syndrome of progressive lenticular degeneration are:

1. Hypertonicity of the muscles, which begins with the limbs and later spreads to the rest of the voluntary musculature with the exception of extrinsic ocular muscles.
2. Tremor is one of the most marked symptoms. It is regular and rhythmic, increased by excitement, attention and voluntary effort. In the advanced stages it involves the neck and trunk muscles.
3. Dysarthria and dysphagia are almost invariably present. The dysarthria is characterized by a slurring element in the speech without the staccato feature of disseminated sclerosis.
4. Hypertrophic cirrhosis of the liver.
5. The occurrence of the disease in adolescence; its tendency to be familial and perhaps hereditary.
6. The absence of pyramidal tract symptoms, such as actual volitional paralysis and increased or pathological deep reflexes.
7. The absence of psychic changes.
8. The absence of somatic sensory changes.
9. The absence of splanchnic motor and sensory changes with the exception of such alterations as are indicated by the hypertrophic cirrhosis of the liver and the marked instability in the vasomotor system especially in the terminal stages of the disease.

Syndrome of the Corpus Striatum (Particularly Affecting the Caudate Nucleus and Putamen). **HISTORY.** The patient, a woman seventy-seven years of age, died after an affliction which had lasted most of her life. Following several convulsions in her fourth year, she was paralyzed on her right side for

many months. In her fifth year she began to make peculiar grimaces and turn her head from side to side. In the course of a year these peculiar movements spread to the arms, body and legs until the several parts of her body were in almost constant motion. These constant spasmodic movements were increased when the patient was excited or attempted any voluntary act. The execution of the abnormal movements seemed to follow some rough plan. The twisting of the head and neck, of the arm, leg and trunk, were repeated in much the same serial order hour after hour. She was subject to unprovoked outbursts of laughter and sometimes would weep in a spasmodic way. Her speech was much disturbed by the constant undulatory movements of the trunk which increased their activity on any attempt to speak. Any movement of the body invariably increased the range and severity of these twisting and squirming motions. The patient's intelligence was good and in spite of her motor defect she was a helpful member of her household and rendered much service during her stay in the hospital. One brother suffered from a mental disease; a cousin was a suicide; her paternal uncle had had an attack of insanity and her father died at an early age from alcoholic excesses.

EXAMINATION. Upon examination two years before her death she was somewhat stooped and had all the appearance of a woman of advanced years. There was a strong scoliosis with the convexity toward the left.

The *somatic motor component* showed that the idiodynamic control of the muscles was intact; reflex control showed some inequality in the deep reflexes on the two sides; the superficial reflexes were present and there were no pathological reflexes in any part of the body. The tonic control of the muscles showed a marked increase in the muscles of the leg, arm and neck, but not sufficient to interfere with voluntary control. Coordinative and equilibratory control of the muscles was defective only as interfered with by the constant abnormal involuntary movements. Automatic associated control showed a marked disturbance in that there was a constant appearance of twisting and squirming movements of the entire body involving



FIG. 517.—Congenital double athetosis in a young woman of twenty-two years. (Déjerine.)

the facial muscles and the tongue as well as those of the neck, trunk, arms and legs, which gave the impression of mobile spasms due to the increased tone of the muscles. These twisting and squirming movements are referred to as athetosis or choreo-athetosis, and they represent the most striking feature in this syndrome. In addition to these irregular involuntary movements there was a slight rhythmical oscillation especially affecting the hand and tongue muscles. This was increased by attention and did not appear during rest. Volitional control was normal except in so far as it was disturbed by the marked degree of hypertonus and the difficulties imposed by the constant athetoid movements. The cranial nerves showed no disturbance except the difficulty in speech referred to which in all probability was due to the hypertonus in the articulatory muscles as well as the presence of the lingual and facial athetosis. There was also a marked degree of dysphagia and some dysarthria.

The *somatic sensory component* showed no defect.

The *splanchnic motor and sensory components* were also normal.

The mental status showed no abnormality.

INTERPRETATION AND ANATOMICAL ANALYSIS. The nature of the lesion in this case was a progressive degeneration beginning early in life. The evidence of the focus of the lesion is furnished by the release from proper inhibition of the paleokinetic system which produced the symptoms resulting in exaggerated automatic associated movements with a more or less marked degree of hypertonus and some tremor. Evidence of circumscription of the lesion is afforded by the absence of any signs referable to the neokinetic system, as the patient did not present in the later stages of her disease any pyramidal tract symptoms. The absence of other motor and sensory symptoms, both somatic and splanchnic, and of mental symptoms, served further to determine the boundaries of the lesion.

DIAGNOSIS AND PATHOLOGY. The diagnosis in this case is a progressive degenerative lesion affecting the corpus striatum and having its greatest intensity in the caudate nucleus and the putamen.

NOMENCLATURE. This is known as the *syndrome of double athetosis*. It is also referred to as the *syndrome of the corpus striatum of Vogt*.

SUMMARY. The chief clinical features of the syndrome of the corpus striatum of Vogt are:

1. Muscular spasms producing athetoid and choreo-athetoid movements.
2. Rhythmical oscillation in the limbs constituting a fine tremor.
3. Exaggeration of automatic associated movements.
4. Spasmodic outbursts of laughing and crying.
5. The absence of paralysis or any evidence of involvement of the pyramidal system.
6. The absence of disturbances in sensibility and the absence of the mental disturbances.

Summary with Reference to the Function of the Corpus Striatum and Symptoms Due to Lesions in It. The functions of the corpus striatum, according to Ramsay Hunt, depend upon the presence of two systems in this

organ. The first of these, the paleostriatal system, is primitive and represented by the motor center of the striate body. The second, the neostriatal system, is represented by small cells. It serves as a controlling and correlating mechanism. The corpus striatum has no direct connection with the cerebral cortex, and its two systems must therefore be controlled through the optic thalamus with which it is closely associated by afferent fibers. The paleostriatal system of large cells has a dual function; first, the production and control of automatic associated movements; second, myotonic stabilization of the muscles which keeps the muscular system in a condition adapted to the needs of the prompt performance of automatic associated movements.

The neostriatal system of small cells serves an entirely different purpose; namely, that of extending the possible combination of automatic associated movements in the same way that the cerebral cortex outside of the motor area elaborates the motor impulses which pass by means of this region to the final common pathway. But the neostriatal system also serves in the essential capacity of inhibiting automatic movements. The necessity of such inhibition has already been pointed out in connection with the transition which occurred in passing from aquatic to terrestrial life.

The paleostriatal system is confined almost exclusively to the globus pallidus. This portion of the corpus striatum, therefore, is fundamentally concerned in the production of automatic associated movements and in myotonic stabilization. The symptoms resulting from destruction of the globus pallidus in degenerative processes would therefore be suppression of automatic associated movements, hypertonus of the body musculature, the production of more or less pronounced attitudes, and tremor occurring in the resting stage of the muscles due to the lack of proper myotonic stability. These symptoms constitute the principal features in the syndrome of paralysis agitans.

The putamen, in contrast to the globus pallidus, contains elements of both the paleostriatal and neostriatal systems, with a slight preponderance of the latter. Disease in the putamen produces symptoms which may closely simulate those of paralysis agitans, but are usually distinguished by the greater degree of hypertonus in the muscles. The caudate nucleus consists in large part of the neostriatal system which acts in an inhibitory manner upon the globus pallidus. The symptoms of disease in this portion of the corpus striatum are due to a liberation of automatic associated movements. It has been suggested that both the paleostriatal and neostriatal systems may be the seat of selective degenerations. Atrophy of the paleostriatal system results in paralysis agitans. Atrophy of the neostriatal inhibitory and coordinating systems produces choreiform movements. In the syndrome of juvenile paralysis agitans, the chief disturbance is in the globus pallidus and results in the suppression of automatic associated movements, hypertonus and a tremor. In progressive lenticular degeneration the pathological process chiefly affects the putamen, but may also extend to the globus pallidus. Its symptoms are suppression of automatic associated movement, pronounced increase in muscle tone, and improper stabilization of the

muscles resulting in tremor. In the syndrome of the corpus striatum in which the lesion most especially compromises the caudate nucleus but may involve the putamen, the symptoms are hypertonus, tremor and choreo-athetosis due to a failure of the inhibitory influence of the neostriatum.

Recognition of the two systems in the corpus striatum and of their tendency to selective involvement by pathological processes offers an unusually helpful suggestion in the study of this complex region of the brain. Although this suggestion cannot be unreservedly accepted at the present time, it provides a working hypothesis, having the support of much clinical experience, from which the boundaries of our knowledge concerning the striate body may be extended.

CHAPTER XLVI

THE ENDBRAIN

CEREBRAL LOCALIZATION—THE SOMATIC MOTOR AREA

Methods by Which Cerebral Localization has been Established. It has been known for many years that all of the areas of the cerebral cortex are not dynamically similar. Functional specialization in certain regions of the pallium has long been a recognized fact out of which has grown the conception of cerebral localization. This conception has been one of slow development. It has not been evolved from any single method of investigation, but depends upon a combination of many procedures.

A casual survey of the cerebral cortex is not in itself suggestive of functional specialization. Gross anatomy, in all probability, would never have supplied a satisfactory interpretation concerning cortical functions, and we should in all likelihood have been in the dark today were it not for the application of the several methods which have gone far in elucidating the functional significance of different areas of the cerebral cortex. Many investigators have given attention to this subject, and the most productive researches, perhaps, are those which employed the following methods:

THE METHOD OF STILLING—INVESTIGATION BY SERIAL SECTIONS. By means of sectioning the central nervous system, especially the brain, it first became possible to gain some conception of its internal structure. As early as 1776 this method had already revealed certain distinguishing features in different areas of the brain. Gennari had recognized the broad band in the calcarine region which now bears his name. This was the first real step toward acquiring a knowledge of the intimate structure of the cortex.

THE METHOD OF GERLACH—HISTOLOGICAL PREPARATION BY MEANS OF STAINS AND CHEMICAL REAGENTS. The next distinct advance came with the application of certain staining methods to sections of the brain. Many investigators have made notable contributions to our knowledge of the nervous system by the application of various staining methods. Among these may be mentioned Weigert and Pal, who, by means of a hematoxylin stain, revealed certain characteristics of the axis cylinder and its medullary sheath. Nissl and Golgi, the first by means of methylin blue and the other by silver impregnation, brought to light many intricate details in the structure of the nerve cells and their processes. In the hands of Cajal, the several methods of cell staining have disclosed the more intimate structure of the neurone and its connections.

THE MYELINOGENETIC METHOD OF FLECHSIG. This means of investigation depends upon the fact that the systems of fibers arising in the central nervous system acquire their myelin sheaths at different periods of develop-

ment. It is believed that a fiber tract or pathway does not assume its responsibilities of conduction until it has become myelinated. A chronological schedule of the myelinization time of the different fiber systems in the nervous system was thus established by Flechsig. This fact made it possible not only to identify certain tracts and pathways, but was still more significant in delimiting discrete areas in the cortex with which these fibers were in connection. By the method of Flechsig, the conception of cerebral localization was given a decided impetus.

METHOD OF EMBRYOLOGICAL ARREST OF GUDDEN. This method of investigation depends upon the correlation of developmental defects in the brain with marked disturbances in the functions of the nervous system. Observations of developmental arrests in certain cortical areas, with coincident disorders of nervous control, have made important contributions to cerebral localization.

THE PHYSIOLOGICAL METHOD. By means of physiological experimentation upon animals, in which either local extirpations or focal stimulation by electrical, thermal and mechanical agents was employed, it has been possible to explore large areas of the cerebral cortex. This method in the hands of many investigators has yielded valuable evidence concerning cortical localization. The most reliable positive results of such experimental investigation have been motor responses to stimulation or the loss of motor control consequent upon extirpation. Only limited areas of the cortex have yielded such results. On the other hand, it has been possible, by a process of exclusion, to determine certain non-excitabile or silent regions of the cortex. By means of focal destructions of cortical areas, physiological examination has shed much light upon the location of the visual, auditory, somesthetic and olfactory areas of the pallium.

THE PATHOLOGICO-ANATOMICAL METHOD OF TÜRCK. This method depends upon the delineation of cortical areas connected with nerve fibers which have undergone degeneration as the result of disease or injury. Pathological interruptions of certain fiber tracts make it possible to trace the degenerative process back to the cells in which the nerve fibers terminate or take origin. This method affords another means of interpreting the significance of cortical areas in the light of the functions of the conduction tracts.

THE CLINICO-PATHOLOGICAL METHOD. This method depends upon the correlation of lesions of the brain discovered postmortem with the symptom-complexes presented by the patient. In this manner such gross lesions as hemorrhages, tumors, cysts or abscesses involving the cerebral cortex have furnished a wealth of material from which invaluable deductions concerning cerebral localization have been drawn.

THE HISTOLOGICAL METHOD. One of the most exact means applied to the investigation of the cortex is the histological method. Among the chief contributors in this field are Brodmann, Kaes, Hammarberg and Campbell, who investigated the several strata of the cerebral cortex in the principal areas and lobes of the brain. The results of these researches have done much

to advance or confirm the conclusions drawn from experimental, clinical, embryological and myelinogenetic investigations.

The classical work of Campbell stands preeminent as one of the most illuminating of all the efforts toward more exact cerebral localization. No better conception may be obtained concerning the histological characters and territorial disposition of the functional regions of the cortex than that afforded by Campbell's observations and conclusions. His work is the basis for the following descriptions of the areas in the pallium.

CORTICAL AREAS DISTINGUISHED BY THE HISTOLOGICAL METHOD

The regions of the cerebral cortex which have been differentiated by the histological method, according to Campbell, include: the precentral motor area and the intermediate precentral area; the postcentral or sensory area and the intermediate postcentral area; the occipital or visual area and the intermediate occipital area; the temporal or auditory area and the intermediate temporal area; the limbic or olfactory area; the insular area (island of Reil); the parietal area; the frontal and prefrontal areas.

Each area is characterized by distinctive histological features which in conjunction with other facts of cerebral localization serve to identify it as a region designed for some particular cortical function. The regional differences which distinguish these areas appear in the several strata of the cells and fibers.

Each functional area of the cortex should be studied with reference to its landmarks, its boundaries and distribution, its cellular and fiber peculiarities and its functional significance.

The Precentral or Motor Area. ITS LANDMARK, THE FISSURE OF ROLANDO. As a result of recent experiments upon the brains of anthropoid apes it has been established that the motor area is situated in close relation to the fissure of Rolando (central fissure), and occupies a large portion of the convolution in front of this fissure. Since the motor area has its chief landmark in the Rolandic fissure, its general extent varies directly with the variations of this fissure. In 20 per cent of human brains the central fissure is confined to the lateral surface of the hemisphere. In 20 per cent it reaches the margin of transition between the lateral and mesial surfaces, while in 60 per cent of cases it actually incises the mesial surface for a variable distance. At its lower extremity the fissure of Rolando approaches the fissure of Sylvius or in 10 to 19 per cent of cases joins it. A deep annectant gyrus usually forms the lower limit of the motor area, so that even in the cases of the Rolando-Sylvian confluence, the precentral cortex is excluded from the basal surface of the brain.

The Rolandic fissure usually presents two flexures, the *superior* and *inferior genu* respectively. The superior genu is situated at the junction of the upper and middle thirds of the fissure, and is in relation with a deep annectant gyrus which is disclosed upon separating the lips of the central sulcus. In some rare instances this annectant comes to the surface, thus

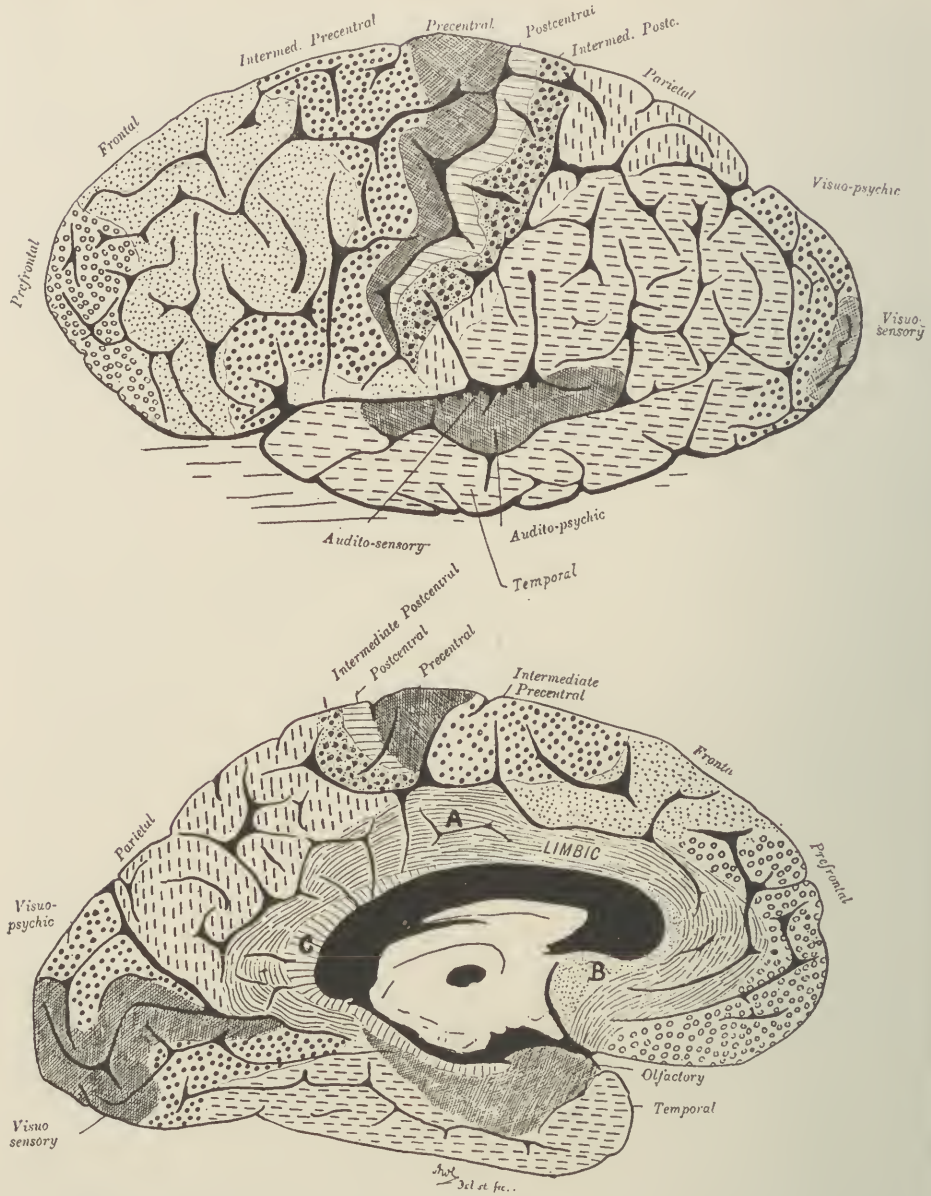


FIG. 518.—Human brain. Tracings of the lateral and mesial surfaces (the former somewhat tilted to show the convexity) of the left cerebral hemisphere, with a representation of the extent of the various areas defined therein, from an examination of cortical nerve fibers and nerve cells. (*Campbell.*)

In a surface diagram it is impossible to give a true idea of the extent of many of these fields, because cortex concealed within fissures cannot be indicated, and unfortunately the figures are especially misleading in regard to some of the most important areas; thus the floor, not the lip, of the fissure of Rolando is the boundary between the precentral and postcentral fields, and accordingly the concealed portion of these areas is almost equivalent to that exposed; the same applies to the calcarine or visuo-sensory field, while that marked "audito-sensory" is almost completely hidden in the Sylvian fissure.

separating the Rolandic fissure into two parts. Topographically, the superior genu marks the transition from the leg to the arm area and the deep annectant gyrus is the divisional landmark between these two functional regions. There is some evidence to indicate that the fissure of Rolando is developed from an upper and lower central sulcus at first separated by a surface con-

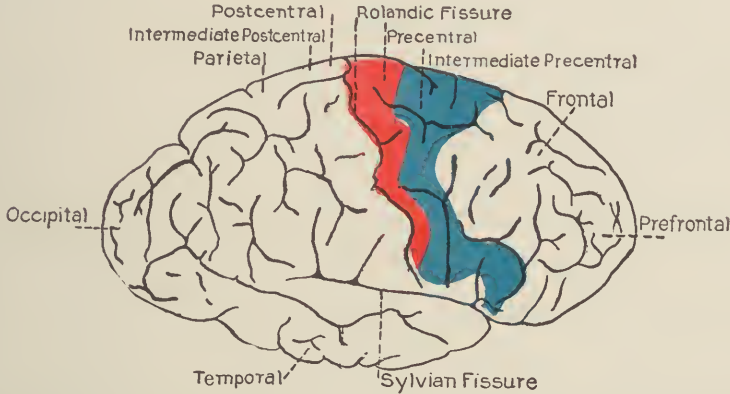


FIG. 519.—Cerebral cortex—mesial surface. Red indicates precentral area; blue indicates intermediate precentral area.

volution. These sulci subsequently become confluent with the resultant submergence of the deep annectant gyrus.

The inferior genu is less conspicuous and also less constant, but when present it appears at the junction of the lower and middle thirds of the fissure and has in connection with it one or two deep annectant gyri.

BOUNDARIES AND DISTRIBUTION OF THE PRECENTRAL AREA. The pre-

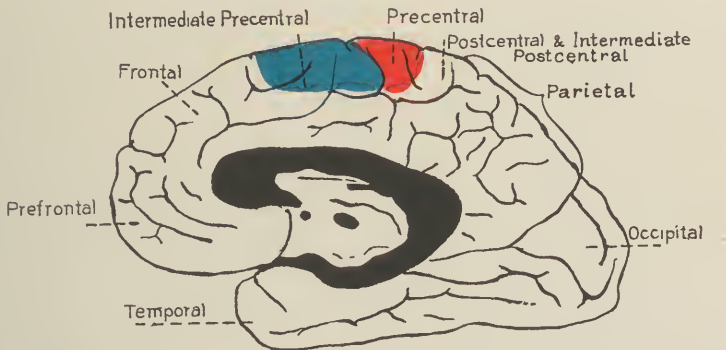


FIG. 520.—Cerebral cortex—lateral surface. Red indicates precentral area; blue indicates intermediate precentral area.

central cortex is situated chiefly upon the lateral surface of the hemisphere extending over a little more than half of the precentral convolution, while upon the mesial surface it occupies an area in the paracentral lobule cephalad of the Rolandic incisure. It extends along the entire cephalic wall of the fissure reaching into its depths almost to the fissural floor. Upon the lateral sur-

face the fissure of Rolando constitutes the caudal boundary of this area, but at this point the type of cortex shows a marked and abrupt transition. The cephalic boundary is less distinct both in the fact that the cortex itself manifests no decided change in type, and also because no topographical line of division exists to demarcate it. Such a boundary may be drawn from histological sections, however, where it appears as a line generally parallel with, and from 1.5 to 2 cm. in front of the fissure of Rolando.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE PRECENTRAL AREA.
The Plexiform Layer. In the precentral area this layer is deeper than in other cortical regions. It is associated with a heavy zonal layer. The cells are small and present no striking features.

The Layer of Small Pyramidal Cells. This stratum does not differ in any essential from that of other areas, and has, therefore, but little interest as a distinguishing feature of this region. Its cells are perhaps not so numerous as in other regions of the cortex, nor do they comprise a stratum which is sharply marked off from the next subjacent layer.

The Layer of Medium-Sized Pyramidal Cells. These elements form a lamina of considerable depth, but are not strikingly different from the corresponding layer in other parts of the cortex. They follow the usual rule of increasing in size the further they are situated from the surface.

The Layer of External Large Pyramidal Cells. This stratum has no distinct line of demarcation. It is developed from the layer above by a gradual transition. The cells for the most part are pyramidal in shape, and in size are from 15 to 20 micra wide and 25 to 30 micra long. They are of the stichochrome type and contain a relatively large nucleus. In themselves they are distinctive of this area neither by reason of their form or arrangement, nor because of the depth of the stratum of which they constitute the chief elements.

The Layer of Stellate Cells. This stratum is distinctive because of its meager development. It is so poorly represented as to be just recognizable, a fact which distinguishes this area of the cortex, since elsewhere the layer is a prominent stratigraphic element.

The Layer of Internal Large Pyramidal Cells. Layer of Giant Cells. The giant pyramidal cells of Betz, also known as the ganglionic cells of Bevan Lewis, identify this area of the cortex beyond all doubt and furnish an absolute guide to the territory and confines of the motor region.

In shape these cells are pyramidal, multipolar elements whose apical dendrites extend into the plexiform layer; their axones enter the medullary substance constituting the chief emissary or motor projection system of the endbrain. Their cytoplasm is abundant and contains a large oval nucleus. The arrangement of the Nissl bodies places these cells in the category of stichochromes. In size they vary from 60 by 25 micra to 35 by 17 micra, depending upon the region of this area which they occupy. Besides these distinctly motor cells of Betz, this stratum also contains pyramidal cells of somewhat smaller dimensions, as well as many stellate

elements. The largest Betz cells are found near the superior longitudinal fissure in the *leg area*, while the smallest cells of this type occupy a position in the *facial area* near the inferior extremity of the motor zone. Betz cells of intermediate size are found in and about the superior genu in the *arm area*. The differences in diameters of these giant pyramidal cells have been explained on the grounds that the greater the distance along which the nerve cell has to transmit its energy, the larger will be the cell body. Obviously, the largest Betz cells should be located in the leg area, since the axones from them must descend to the lumbo-sacral segments of the cord, while the smallest cells should occupy the facial and tongue areas whose axones descend only as far as the pons and medulla. It is probable that the neurones which control the oculomotor apparatus are the smallest of this type of cortical cell.

Another feature which distinguishes these cells is their arrangement in clusters of three to six. These groups of Betz cells are irregular, but the Betz cluster is so distinctive a characteristic of the motor area that it serves as one of the most reliable topographical guides to cortical localization.

It has been estimated that there are approximately 25,000 cells of Betz in the motor cortex of either side. This estimation has an interesting bearing upon the number of motor cells calculated to be in the ventral gray column on one side of the spinal cord,

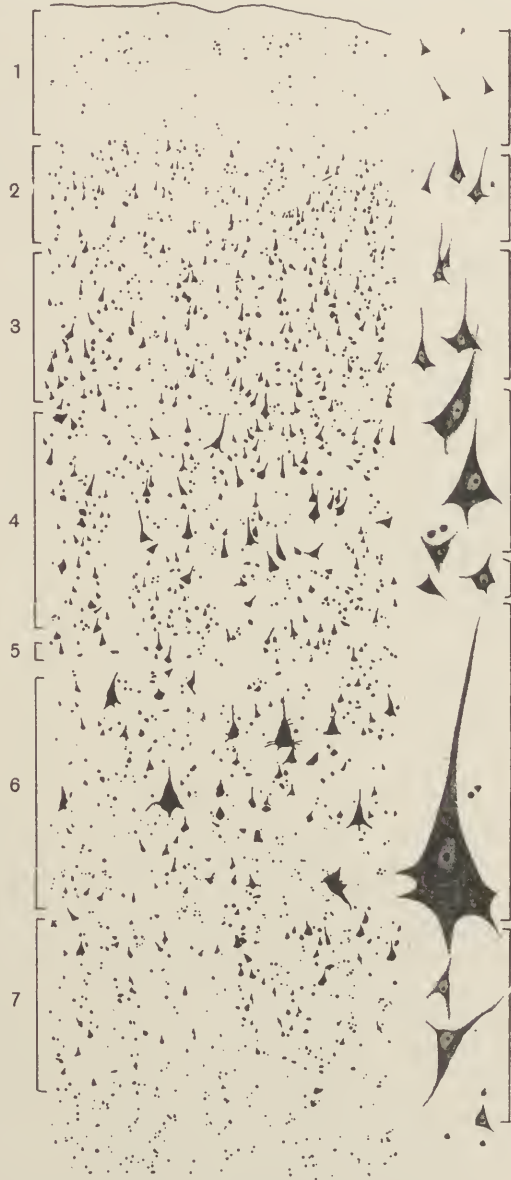


FIG. 2.

FIG. 521.—Stratigraphic analysis of the cells in the precentral or motor area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells—giant cells of Betz. 7. Layer of fusiform cells.

i.e., between 240,000 and 300,000. From these figures it appears that the ratio between the Betz cells and the motor cells of the spinal cord is 1 to 10. Each giant cell of the cortex, in consequence, must be in relation with at least ten ventral column cells of the cord.

The number of Betz cells varies considerably in different parts of the motor cortex. Beginning at the upper extremity of the Rolandic fissure, Campbell has estimated the number of cells every 5 mm., as a result of which he has formulated the accompanying table.

TABLE SHOWING NUMBER OF BETZ CELLS EVERY 5 MM.

Upper extremity of central fissure	2 cells	Mesial surface
5 mm. from upper extremity of fissure	19 cells	
10 mm. from upper extremity of fissure	30 cells	
15 mm. from upper extremity of fissure	32 cells	
20 mm. from upper extremity of fissure	30 cells	
25 mm. from upper extremity of fissure	41 cells	From margin of hemisphere to deep annectant
30 mm. from upper extremity of fissure	20 cells	
35 mm. from upper extremity of fissure	6 cells	
40 mm. from upper extremity of fissure	9 cells	
45 mm. from upper extremity of fissure	3 cells	
50 mm. from upper extremity of fissure	3 cells	Annectant gyrus
55 mm. from upper extremity of fissure	17 cells	
60 mm. from upper extremity of fissure	5 cells	
65 mm. from upper extremity of fissure	10 cells	
70 mm. from upper extremity of fissure	11 cells	
75 mm. from upper extremity of fissure	3 cells	
80 mm. from upper extremity of fissure	4 cells	
85 mm. from upper extremity of fissure	4 cells	
90 mm. from upper extremity of fissure	0 cells	

The deep annectant gyrus in relation with the superior genu of the central fissure is notable for the small number of Betz cells contained in it.

Layer of Spindle-Shaped or Fusiform Cells. This stratum of the cortex has little importance in the differentiation of the motor area. Its cells are fusiform, polymorphous and triangular in shape, similar in all respects to the cells encountered in this layer in other regions.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE PRECENTRAL AREA.

The Zonal Layer. This fiber stratum in the outermost medullary layer contains a few non-varicose delicate fibers. The deeper portion of the zonal layer is especially well developed over the entire precentral area and is discernible even by the unaided eye. Its depth is 68 micra; its boundaries are sharply defined.

The Supraradiary Layer. This stratum is relatively deep in the precentral area. The fibers are largely of the finer type with many varicosities. Neither the line of Bechterew nor of Kaes may be identified.

Layer of Baillarger. This distinctive stratum of the cerebral cortex is difficult to identify in the motor area, as it is obscured by the great wealth of fibers in the adjacent strata.

Layer of Radiations—Radiary Layer. The unusual development of this zone is the most pronounced feature in the fiberization of the motor cortex.

This is due to the fact that many large axones are in this region, entering the major projection system of the endbrain, and also the fact that a vast number of fibers enter this area from other regions of the cortex.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES OF THE PRECENTRAL AREA. The principal peculiarities of the motor cortex are: (1) The marked depth of the plexiform layer; (2) the meager development of the stellate layer; (3) the presence of the giant cells of Betz which are arranged in clusters; (4) the depth of the zonal layer; (5) the lack of definition in the line of Baillarger, and (6) the great wealth of fibers in the radiary layer.

FUNCTIONAL SIGNIFICANCE OF THE PRECENTRAL AREA. *Volitional Control.* The motor area of the cerebral cortex gives rise to the axones which form the pyramidal tract. This connection brings the Betz cells of the cortex into direct communication with the somatic motor cells of the brainstem and cord. In consequence of the influence which the motor cortex exerts upon the somatic final common pathway, the skeletal muscles are brought under volitional control and so guided in their activities as to execute the dictates of the will. The motor area itself, as it officiates in dispatching volitional impulses, is influenced by many adjacent and distant areas of the cortex. Each impulse destined to initiate and carry through some volitional act is a composite of a vast number of stimuli convergent upon the cells of Betz. These cells, although they serve for the final transmission of volitional control, are activated in this process from other sources and probably play but a small rôle in the actual incentive, conception and formulation of volitional action. They do actually transmit the motion

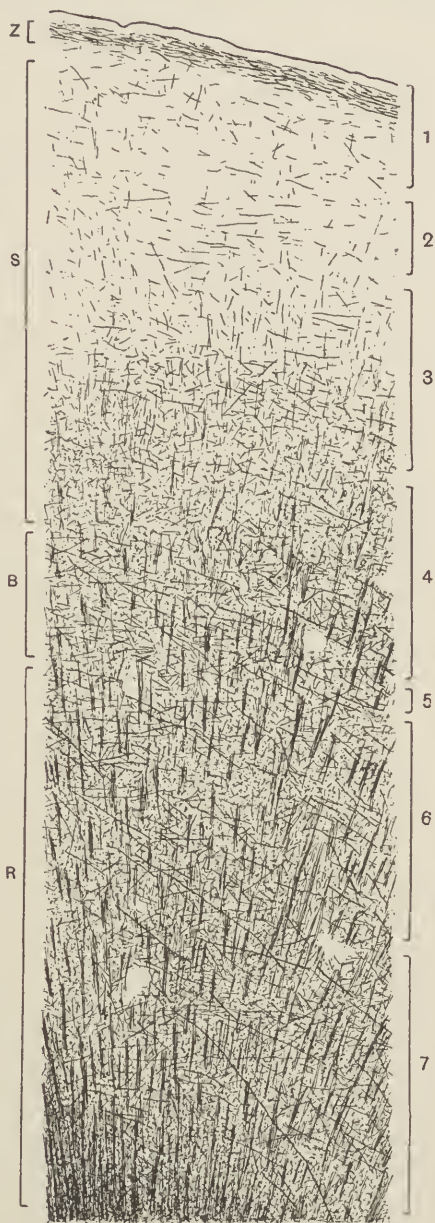


FIG. 522.—Stratigraphic analysis of the fibers in the precentral or motor area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—line of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

formulae for the various skilled acts, but these formulae are in turn prepared and advanced to the motor cells ready for transmission. It is probable that some portion of nearly every special area in the cerebral cortex participates in the formulation of the motor incentive, conception and purpose of every volitional performance. In some instances visual activity may be dominant in this formulation; but auditory and somesthetic sensibility, even gustatory and olfactory sensations, may play some part in the essential synthesis necessary to a given act.

The constituents of these motor syntheses may vary according to the character and fundamental associations of the act; the dominance of some one form of sensibility may usually be recognized in each set. Thus in the skilled performances of speech it is possible to discern the dominance of the sense of hearing as the chief sensory constituent of the speech synthesis. In reading aloud, on the other hand, vision is probably the more dominant element, although in both of these volitional acts, muscle and joint sensibility makes an essential contribution. The motor area of the cerebral cortex is, in this light, the agent or intermediary which serves to transmit complex motion formulae whose patterns have already been prepared.

Inhibition. The motor cortex seems to contribute an essential element to another important activity, *inhibition*. The exact nature of this function of the cortex is not fully understood. Experimental and clinical evidence furnishes convincing reasons for the conclusion that the motor cortex, among other parts of the brain, is responsible for the myotonic condition of the muscles. When this area of the cortex is normally active and exerting its influence upon the final common pathway, the skeletal muscles, unless otherwise defective, manifest a state of tone which is best adapted to the purposes of volitional action. The muscular tissue, under these circumstances, is neither too much relaxed nor too strongly contracted. It is maintained in that ideal condition of tone which permits the expression of the will in the most economic manner. If the muscles were normally held in a state of contraction which offered undue resistance to volitional action, the expenditure of energy necessary to overcome such resistance would be excessive and wasteful. On the other hand, if the muscles were normally over-relaxed, it would require unnecessary exertion on the part of the will to overcome this slack before the desired performance began. The motor cortex seems, therefore, to be capable of maintaining the muscles in a desired state of tone midway between the extremes of excessive contraction and undue relaxation. It holds the muscular tissue ready to do the bidding of the will in the most expeditious manner.

When the motor area of the cerebral cortex is defective or destroyed, this moderating influence upon the final common pathway is lost and the muscles become contracted to an unusual degree. The resulting condition is known as *hypertonus* or *spasticity*. It causes the part connected with these muscles to be held rigidly in a more or less fixed position, producing oftentimes the appearance of actual deformity. The explanation of this rigidity in the muscles is found in the fact that the primary reflex arc permits the

incessant and constant flow of afferent stimuli which are immediately converted into motor impulses and determine muscular contraction. The influence of the motor cortex appears to be the suppression of the myotonic effects of this constant flow of impulses through the primary reflex arcs. It holds simple reflex action in abeyance by exerting an inhibitory control over the final common pathway. The precise nature of this function of the motor cortex cannot be exhibited at the present time, but as a clinical phenomenon it may be accepted as a definite activity of the motor area.

STIMULATION OF THE MOTOR CORTX. The motor area when stimulated by electricity or other means discloses the fact that it is subdivided into subsidiary areas which have volitional control over special parts of the body. This subdivision based on electrical stimulation leads to the recognition of the following secondary areas: (1) Foot, leg and thigh area; (2) trunk area; (3) shoulder girdle area; (4) hand, forearm and arm area; (5) facial

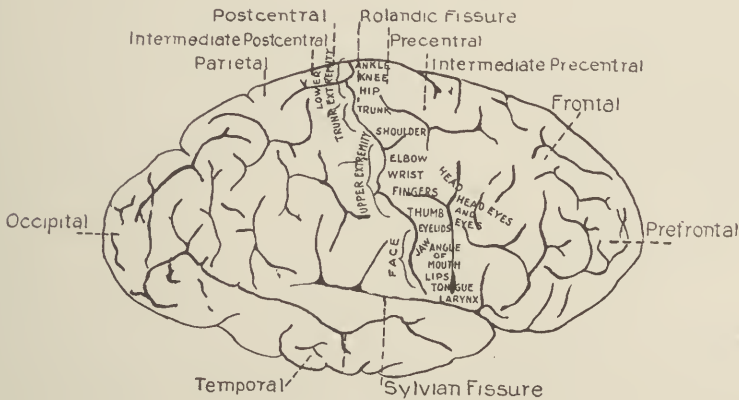


FIG. 523.—Functional localization in the precentral convolution. (Campbell.)

area; (6) lingual area; (7) palato-pharyngo-laryngeal area; (8) oculogyric and cephalogyric centers.

1. The foot, leg and thigh area is situated in relation with the upper extremity of the Rolandic fissure and occupies the cortical zone both on the mesial and lateral surfaces of the brain. The portion of the motor area upon the mesial surface in the paracentral lobule contains the Betz cells which control volitional movements of the toes and ankle. The area of motor cortex on the lateral aspect caudal to the end of the superior frontal fissure contains the cells which control movements at the knee and hip, the knee area being the more superior in position.

2. The trunk area occupies the region bounded above by the hip center and below by the shoulder center.

3. The shoulder girdle area is situated immediately caudal to the posterior extremity of the middle frontal gyrus.

4. The arm, forearm and hand area, which includes the controlling elements for the thumb and fingers, is situated in relation with the inferior

genu of the precentral gyrus. It extends downward to the upper extremity of the inferior genu of the precentral convolution. It contains special centers for movements at the elbow and wrist and in the fingers and thumb. These centers occupy areas topographically related to each other in the order enumerated from above downward.

5. The facial area is in relation with the inferior genu of the precentral gyrus. The motor cells controlling the supra-orbital portion of the occipito-frontalis, the corrugator supercilii and the muscles of the eyelids are collected in a small area immediately ventral to the center for the thumb. The center for the occipito-frontalis muscle is bilateral. It has a representation in the motor areas of both hemispheres. This is the only portion of the facial musculature which has a bilateral innervation from the motor cortex. The clinical importance of this fact should be borne in mind, since it serves to differentiate between the central and peripheral types of facial palsy. In facial paralysis of the central type the occipito-frontalis muscle is spared on the paralyzed side. In the peripheral type the entire musculature including the occipito-frontalis is affected by the paralysis.

6. The lingual area is situated immediately ventral to the facial area. It supplies the tongue with a unilateral innervation.

7. The palato-pharyngo-laryngeal area occupies the ventral extremity of the precentral convolution. As in the case of the middle and lower facial musculature and the tongue, its innervation of the muscles of the palate, pharynx and larynx is unilateral.

8. The oculogyric and cephalogyric area is situated in a small frontal extension of the precentral gyrus immediately in front of the area for the upper extremity. The exact limits of this region are difficult to determine, but experimental stimulation of the area in higher apes consistently produces conjugated movements of the eyes in all directions as well as movements of the head.

Experimental destruction of any of these special areas of the motor cortex causes a complete paralysis of the spastic type. This loss of volitional control is best demonstrated in the foot, leg and thigh areas, and also in the finger, hand, forearm and arm areas. Destruction of a given region is attended by paralysis with hypertonicity, due to a loss of volitional control and inhibition.

SYNDROMES OF THE MOTOR CORTEX. Depending upon the character of the pathological process, two types of symptom-complexes may develop.

The *syndrome of irritation* is caused by irritative lesions affecting the motor cortex, as a result of which the patient manifests paroxysmal attacks of local or diffuse spasms in the muscles corresponding to the affected areas. These spasms are tono-clonic in character. They may be limited to the face, upper extremity, trunk, or lower extremity. In certain instances the spasm may implicate one group or several groups of muscles in these parts. Usually the spasm begins in some definite group of muscles, as for example, those of the hand, and spreads in regular succession to the next adjacent part until the entire half of the body is convulsed. This is known

as *Jacksonian Epilepsy*. The patient does not lose consciousness during the attack which may last a few moments or several hours. In many cases, when the spasm spreads rapidly over one half of the body, it finally extends until the entire musculature is involved in a general convulsion which is attended with loss of consciousness. Irritative lesions of the motor cortex due to any cause may produce this syndrome. Under certain conditions an appreciable degree of paralysis follows after the spasms subside, the duration of which may be several hours or days.

The *syndrome of destruction* is caused by pathological processes which more or less completely destroy the motor cortex. Such lesions produce a loss of volitional control, so that the patient is unable to move the paralyzed parts at will. The paralysis is attended, however, by a pronounced increase in muscle tone which is often so extreme as to occasion contractural positions in the paralyzed parts. The upper extremity may be held in a rigid position of adduction with flexion at the elbow, wrist and finger joints. The lower extremity may present similar spastic involvement. In some instances the upper ex-

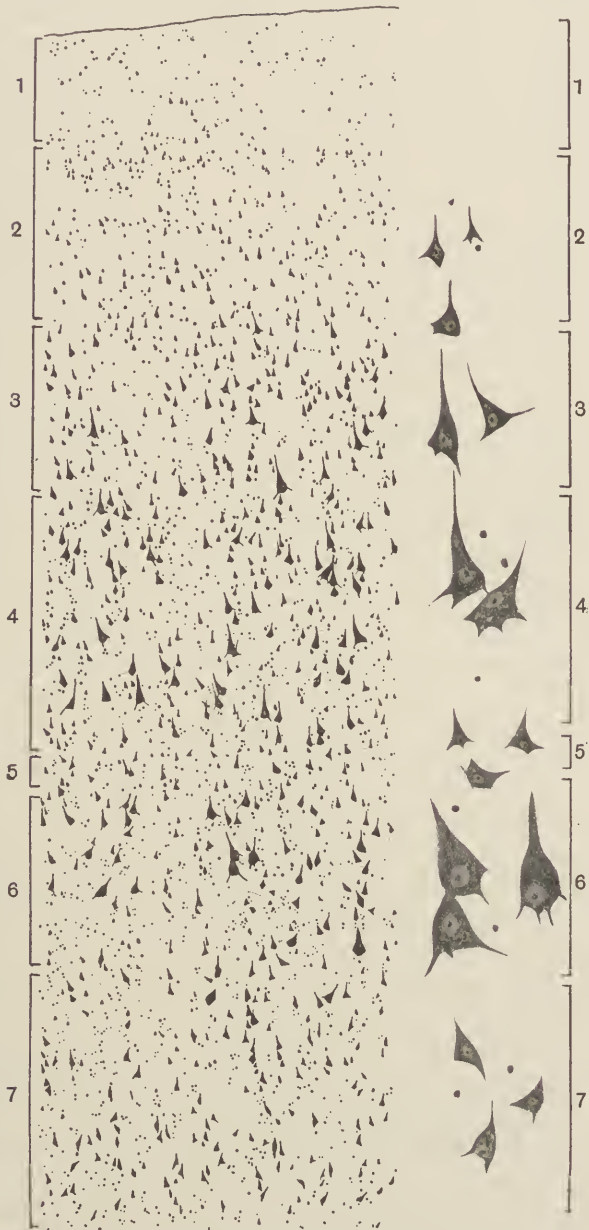


FIG. 524.—Stratigraphic analysis of the cells in the intermediate precentral or psycho-motor area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

tremity alone is involved in the spastic paralysis; less commonly the leg alone may manifest the paralysis (monoplegia). The most usual type of involvement is a spastic paralysis of one half of the body (hemiplegia). The hypertonus of the muscles is accompanied by an increase in the deep reflexes, with the appearance of pathological reflexes and the disappearance of the superficial reflexes. No sensory disturbances are present.

The Intermediate Precentral or Psycho-Motor Area. **BOUNDARIES AND DISTRIBUTION.** This area of the cortex occupies a zone in the frontal lobe immediately in front of the precentral area. In width it varies from 2.5 cm. at its upper extremity to 1 cm. near its middle, and 2.5 or 3 cm. at its lower extremity. It reaches downward and forward to the orbital surface of the frontal lobe. The frontal boundary of this zone is not constant and its delineation therefore is represented by an approximate or average line. On the mesial surface of the hemisphere the frontal boundary line is situated 3 cm. in front of the precentral area and is continued ventrally into the calloso-marginal fissure. At and near the vertex of the lateral surface the line extends into the superior frontal gyrus for a distance varying from 5 to 5.5 cm. from the Rolandic fissure. On passing into the middle frontal convolution the line retreats considerably toward the central fissure, from which it is separated by an average distance of 2.5 cm. At its lower extremity the frontal boundary line of this area sweeps forward again further into the frontal lobe, crosses the inferior precentral sulcus in such a way as to include most of the inferior frontal gyrus with some, but not all, of the pars basilaris and the whole of the pars triangularis in the intermediate precentral area. Still more ventrally the line turns inward and extends along the orbital operculum until it reaches the transverse orbital sulcus.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE INTERMEDIATE PRECENTRAL AREA. *The Plexiform Layer.* This stratum of cells is slightly more shallow than in the precentral area and also contains few cells. In general character and appearance it closely resembles the motor cortex.

The Layer of Small Pyramidal Cells. The cells in this stratum bear a close resemblance to similar elements in the precentral cortex. They are more densely crowded together and for this reason probably more numerous than in the motor area.

The Layer of Medium-Sized Pyramidal Cells. A slight increase in the thickness of this stratum is the only feature which distinguishes it from the corresponding layer of the precentral area.

The Layer of External Large Pyramidal Cells. The pyramidal cells of this stratum resemble in all details those in the corresponding layer of the precentral area. They are equal in size, similar in the character and arrangement of their chromophilic substance, and as numerous as the pyramidal cells of the motor cortex. Some topographical variations are of importance. The portion of the intermediate precentral cortex bordering upon the precentral area contains cells in this stratum which are appreciably larger than those occupying a more frontal position. These cells also decrease in

size in passing from the upper to the lower extremity of the area. In the main, the layer of external large pyramidal cells in the intermediate precentral area bears such close resemblance to that in the precentral cortex that it is difficult to distinguish between them. This resemblance serves the important purpose of differentiating between the intermediate precentral and frontal areas and of establishing the general identity of the motor and moto-psychic areas of the cortex.

The Layer of Stellate Cells. This stratum contains fewer nerve-cells than the corresponding layer of the precentral area. The cells are pyramidal, stellate and polymorphous. The feeble development of this layer is a characteristic of the intermediate precentral and the precentral areas.

The Layer of Internal Large Pyramidal Cells. The resemblance between the intermediate precentral and precentral cortex ceases with apparent abruptness in this stratum. The absence of the giant cells of Betz is a fundamental point of difference. Large pyramidal or pyriform cells, however, are present in the intermediate precentral cortex. They are not so large as the Betz cells, and in fact are appreciably smaller than the cells in the external large pyramidal layer. The large pyramidal elements in the internal layer are less numerous and more scattered than in the precentral cortex.

The Layer of Fusiform Cells. This stratum is distinct and deep. It contains many fusiform and polymorphous cells arranged in columns which are determined by the radiations of Meynert. It does not, however, lend any distinctive feature to this area.

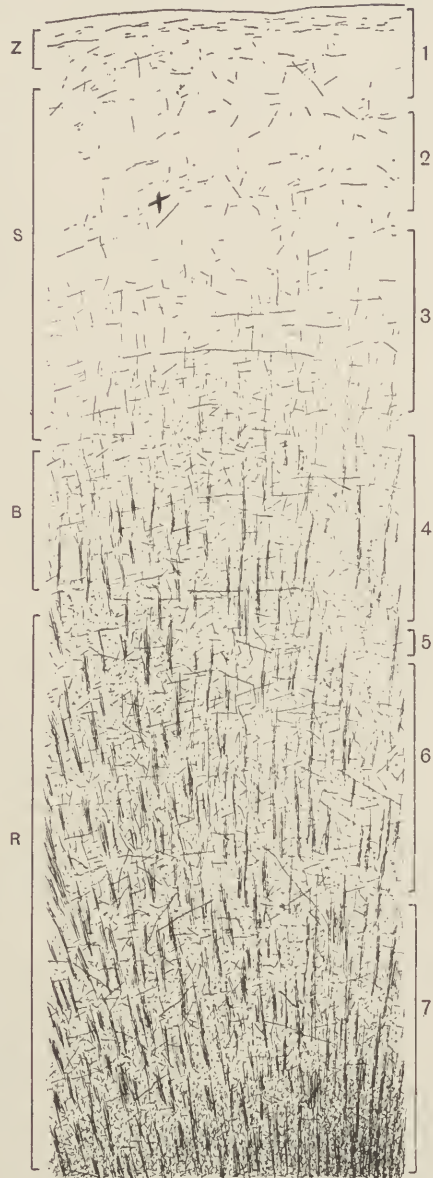


FIG. 525.—Stratigraphic analysis of the fibers in the intermediate precentral or psycho-motor area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE INTERMEDIATE PRECENTRAL AREA. *The Zonal Layer.* This stratum of fibers, in passing from the motor cortex, is marked by a pronounced diminution in thickness. It loses its density, and its lower boundary becomes poorly defined. It contains fine varicose fibers with a few coarser fibers. The large smoothly myelinated axones characteristic of the motor cortex are almost entirely absent.

The Supraradiary Layer. This stratum contains fewer fibers than in the precentral area. The fibers are largely of the fine, short variety and pass in all directions, having for the most part a transverse course. Occasional fibers, apparently from cells of Martinotti, are prominent because of their large size.

The Layer of Baillarger. This layer, although poorly defined at its edges, is of considerable depth. It contains short, fine fibers, transversely disposed with some long, medium-sized non-varicose elements which give prominence to this line. There is some tendency toward reduplication of the line of Baillarger in this area. The second line, however, is not so deep nor so conspicuous as the first.

The Layer of Radiations—Radiary Layer. This stratum is less well developed than in the precentral area. The scarcity of the large medullated fibers in the radiations of Meynert seen in the motor cortex accounts in large measure for the lessened prominence of this layer. The interradiary plexus consists of a dense mass of fine fibers. The association fibers are much reduced in number when compared to those of the precentral area. They are, however, more numerous than in most other areas of the cortex.

SUMMARY OF THE CHIEF STRATIGRAPHIC FEATURES OF THE INTERMEDIATE PRECENTRAL AREA. In general, the intermediate precentral area is a much more feebly developed replica of the precentral type of cortex. All of its chief characteristics, both in cells and fibers, ally it with the motor cortex to which it appears as an ancillary division. The strong histological resemblance in type between these two areas leaves little room to doubt their close physiological association. Certain features of the intermediate precentral cortex, however, cause it to stand out in contrast to its adjacent allied area. The absence of the giant cells of Betz is a distinguishing feature. The lack of large medullated fibers in the radiary zone is also distinctive. The depth of the plexiform layer, on the other hand, together with meager development of the stellate layer and the lack of definition in the line of Baillarger, are characters in which the intermediate precentral area corresponds closely with the precentral cortex.

FUNCTIONAL SIGNIFICANCE OF THE INTERMEDIATE PRECENTRAL AREA. *Moto-Psychic Area.* The motor cortex with its projection system of fibers, the pyramidal tract, forms the *final common pathway of volitional control*. In the same manner that the cells of the ventral gray column receive regulating impulses from many different sources, the motor cortex likewise receives modifying influences from many other cortical regions. These influences condition the activity of the motor cells in the cortex, making possible the complex responses of volitional control.

The complexity of volitional regulation over motor activity, although long recognized, still defies analysis in its finer details. Certain elements in it, however, may be discerned in the light of experimental and clinical experience.

The Incentive Synthesis. In every voluntary performance it is possible to detect an incentive which in itself is a composite of nervous impulses. This composite provides the necessary activating influence without which no voluntary act may be performed.

The Motor Purpose. In addition to the incentive synthesis, voluntary action is carried on under the influence of a definite purpose which requires still another combination of nervous impulses.

The Motor Concept. Volitional performance also depends upon a conception of the act to be performed; that is, the proper recognition of the parts of the body to be employed, the rapidity of action, the degree and extent of motion necessary for the achievement of the purpose.

Not only must the incentive synthesis, motor purpose and motor concept be present in order that the volitional act be carried through to its end, but all of these complex combinations of sensory impulses require the formulation of the component acts entering into the execution of the purpose. In other words, every volitional motor purpose has a definite pattern which selects the essential muscle groups participating in the act and predetermines the serial order, force, rate and duration of their contraction to the end that the energy expended may be adequate to the purpose. In handwriting, for example, certain muscle groups in the hand, forearm, arm and shoulder are selected to take an active part in this performance. The serial order of contraction in the various groups of the upper extremity is prearranged, as well as the force of contraction, its duration and rate. This is the motor pattern or *motion formula*. All skilled acts require such a pattern. This formula, however, is not inherent in the brain cells, but must be acquired through repetition and persistent application. The child in learning to write gives a clear demonstration of the underlying process necessary to the development of handwriting. Eventually, after many trials and errors which at first result in awkward and often ineffective production, the formula for chirography develops in the brain, and thereafter, during health and the intact condition of the cortex, this formula remains as one of the motor characters of the individual. Every skilled act is acquired in this manner, and when acquired determines a definite motion formula which has been impressed upon the brain. It is in this respect that the human brain differs most from that of the lower animals. The cortical cells covering a large area are capable of acquiring numerous motion formulæ for the performance of many specially skilled acts. In this sense, the human cortex has a great degree of *teachability*. Hence it is that the range of skilled acts has reached the culmination of achievement in man.

Such evidence as may be deemed reliable at present seems to indicate that the intermediate precentral area of the cortex is the region in which the motion formulæ for skilled acts are constructed and retained. When the

individual, as the result of a repeated execution of any skilled performance, has attained a degree of relative perfection in execution, the condition is known as *eupraxia* (*eu*, perfect or good; *praxis*, performance). Eupraxia for all skilled acts depends upon the intact condition of the intermediate precentral area. In this region of the cortex there is a deposition of centers for the control of what Hughlings Jackson has termed the "higher evolutionary movements." These movements, by their nature, represent the highest achievements of volition. The centers for this control in the intermediate precentral cortex follow the same order from above downward as that observed in the motor cortex; *e.g.*, leg, trunk, arm, face, tongue and larynx.

SYNDROMES OF THE MOTO-PSYCHIC AREA. When the region of the cortex which controls skilled acts becomes defective, due to disease or injury, the patient is no longer able to perform acts which he has acquired through repetition and application. He may attempt to write or to employ his hand in the performance of some other skilled act, but the accomplishment is imperfect or impossible. This is not because any of the muscles are actually paralyzed, for when the attempt is made, the patient is able to produce a normal contraction in individual muscles or in groups of muscles. When, however, he attempts to combine the action of the several muscle groups necessary for the performance of a particular skilled act, it becomes apparent that he has lost his motion formula and is no longer able to transmit to the muscular tissue that pattern of motor impulses which controls the serial order of muscular contraction, its rate, force, extent and duration. This defect is known as *motor apraxia*.

There are other forms of this type of motor disturbance in which the patient is not able to translate the dictates of the will into proper motor responses. He may lose the conception of the act and in attempting to write, execute a series of movements which bear no relation to this act whatsoever. This defect is known as *ideo-motor apraxia*, in which the patient has lost the motion concept.

Still another type of apraxia is that in which the patient can no longer appreciate the purpose of his voluntary action; as, for example, he is told to light his cigar and puts both the match and the cigar in his mouth at once. This is known as *ideatory apraxia*. Ideatory and ideo-motor apraxia depend upon disturbances in other parts of the pallium. Motor apraxia, on the other hand, arises from lesions in the intermediate precentral area.

Special Forms of Motor Apraxia. The most highly developed of all skilled acts is speech, which depends upon the composite muscular activity of the larynx and pharynx, palate and tongue, lips, cheeks and jaws. The respiratory muscles also should be included in the muscular effectors participating in speech. Lesions in the lower portion of the intermediate precentral area corresponding to the *frontal operculum*, and long known as the *area of Broca*, give rise to a type of apraxia called *motor aphasia*. In this condition the patient suffers from an inability to speak. This is not due to paralysis, for he is able at will to produce contraction in the larynx and pharynx, in

the palate and tongue, in the lips, cheeks and jaws. His respiratory mechanism is likewise normal. Yet it is impossible for him to combine the muscular contractions of these several parts to perform the specific activities necessary to speech production. He retains a clear conception of the purpose to which he directs his will, and likewise a conception of the anatomical parts to be used in speech. But his motion formula has become deranged or has been ablated to such an extent that he is no longer able to make the proper muscular combinations necessary to articulation. Concerning this type of aphasia there has been extensive controversy, and there are those who with much authority refute the idea that Broca's area represents the center controlling the skilled act of speech. On the other hand, clinical experience at least speaks strongly in favor of this supposition which may, therefore, be retained as a working hypothesis until our knowledge of the cerebral cortex has been extended beyond its present limits.

A similar condition of apraxia affects the region of the intermediate precentral area governing the movements of the hand and results in a motor defect called *agraphia*, or the inability to write. This is a much less common defect than motor aphasia, but like the latter it depends upon a loss or defect in the motion formula necessary to chirography. It is a form of motor apraxia involving the specific act of handwriting. The patient shows no paralysis in the muscles usually employed for this skilled performance, and still retains his motion concept and an appreciation of the motor purpose.

Aphasia and apraxia in right-handed individuals depend upon centers in the intermediate precentral cortex of the left side, and in left-handed individuals these centers are situated in the right side of the brain.

The intermediate precentral area may be regarded as the portion of the cerebral cortex which controls skilled movements through the proper correlation of their motor formulæ. Its normal activity results in eupraxia. Defects in it give rise to motor apraxia, special forms of which are motor aphasia and agraphia.

CHAPTER XLVII

THE ENDBRAIN

CEREBRAL LOCALIZATION. THE SOMESTHETO-SENSORY, VISUAL AND AUDITORY AREAS

The Postcentral or Somestheto-Sensory Area (The Body Feeling Sensory Area). The somestheto-sensory or primary sensory area lies immediately caudal to the fissure of Rolando, forming a topographical counterpart to the precentral convolution. The type of cortex in this region is strikingly different from that of the precentral area, and its histological differentiation suffices to indicate a pronounced difference in function.

BOUNDARIES AND DISTRIBUTION OF THE POSTCENTRAL CORTEX. The postcentral type of cortex is distributed over the anterior half of the postcen-

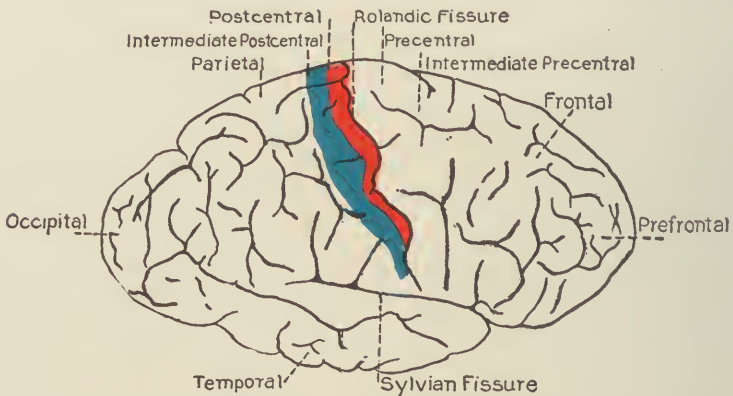


FIG. 526.—Cerebral cortex—lateral surface. Red indicates post-central area; blue indicates intermediate postcentral area.

tral or ascending parietal convolution. It occupies the convex surface of the hemisphere and crosses the upper margin at the vertex. Here it passes over to the mesial surface of the hemisphere where it covers a tongue-like area in the paracentral lobule immediately caudal to the upper extremity of the fissure of Rolando. Its cephalic boundary on the mesial surface is the upper extremity of the precentral area. Below and behind, it is embraced by the intermediate postcentral area. In those instances in which the fissure of Rolando does not incise the margin of the hemisphere, a postcentral strip of cortex appears on the mesial surface having as its cephalic boundary a line projected downward from the dorsal extremity of the central fissure and parallel with the upturned portion of the callosomarginal fissure. On the lateral surface the caudal wall of the fissure of Rolando contains the postcentral

type of cortex. The surface of the postcentral convolution shows a change from the postcentral to the intermediate postcentral type which, however, is gradual and hence without definite line of demarcation. The major portion of the postcentral cortex lies within the fissure of Rolando, for which reason it is difficult, in a surface representation, to give an adequate idea of the extent of this area.

STRATIGRAPHICAL DESCRIPTION OF THE CELLS IN THE POSTCENTRAL AREA. *The Plexiform Layer.* This stratum appears shallow as compared with the precentral cortex. Preparations showing the cellular constituents reveal no marked characteristics in its constituents.

The Layer of Small Pyramidal Cells. This stratum is deeper than that of the corresponding precentral layer. Its cells are more numerous and give the region the appearance of greater cellular density. The cells, in size and shape, resemble in detail those of the corresponding layer in the precentral cortex.

The Layer of Medium-Sized Pyramidal Cells. This stratum is similar in its general character to that of the precentral cortex, although it is appreci-

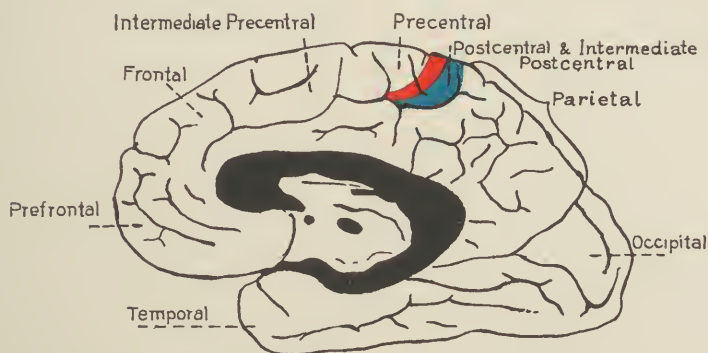


FIG. 527.—Cerebral cortex—mesial surface. Red indicates postcentral area. Blue indicates intermediate postcentral area.

ably more shallow, due apparently to the more extensive development of the next deeper layer.

The Layer of External Large Pyramidal Cells. In this stratum important differences appear which distinguish the postcentral from the precentral type of cortex. The cells are larger and more numerous. They form a stratum .40 mm. in depth in which there is a more definite stratification of the cellular elements. In size the individual cells measure from 22 to 43 micra. They are elongated and pyriform, have three or more distinct processes connected with the base and sides of the cell body, and a strongly developed apical process which attenuates gradually but is of great length and may be traced for 200 micra. Chromophilic bodies in the cytoplasm may be identified, but they are relatively feeble in their staining properties. In addition to these large pyramidal cells there are others similar in shape but of even greater

diameters. These cells contain denser masses of chromophilic substance and

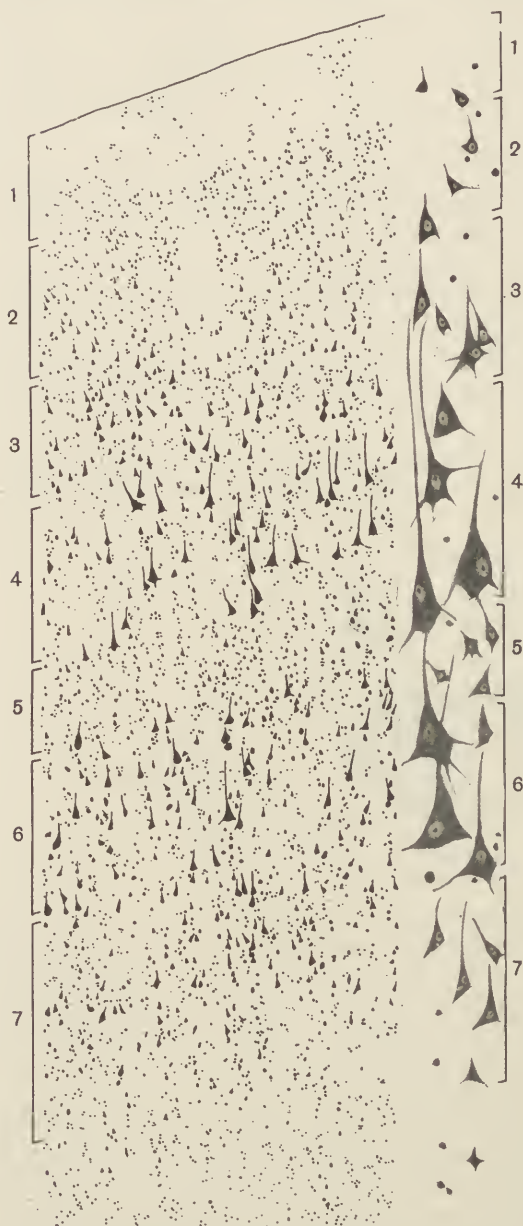


FIG. 528.—Stratigraphic analysis of the cells in the postcentral or somesthetic-sensory area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

The apical dendrite tapers gradually, while that of the Betz cell is marked

of chromophilic substance and hence stain more intensely. They resemble an elongated Betz cell. On the average they measure 30 by 75 micra. These cells are most numerous in the paracentral lobule where their proportion is 1 to every 5 of the large pyramidal cells of this layer. On the lateral surface the proportion is 1 to 20 and passing downward along the postcentral convolution the cells gradually disappear.

The Layer of Stellate Cells.

The marked development of this stratum is one of the distinguishing features of the postcentral cortex. It is .23 mm. in depth and contains many small, deeply staining cells densely packed together. In comparison with the meager development of the stellate layer in the precentral cortex, the prominence of this stratum is a distinctive feature in the postcentral area.

The Layer of Internal Large Pyramidal Cells. This stratum also forms a distinguishing feature in the postcentral area. The absence of the giant cells of Betz is the essential point of difference. The cells themselves in this area are 20 by 50 micra, which is a size well below the diameters of the average giant cells of Betz. In shape, these cells differ from those in the corresponding layer in the precentral area. They are pyramidal, whereas the Betz cells are pyriform.

that of the Betz cell is marked

by a rapid attenuation. The cells of the postcentral area are richly supplied with chromophilic elements which in part obscure the outlines of the nucleus. In no portion of the postcentral area do these giant cells tend to collect in clusters as is the case with the Betz cells.

The Layer of Spindle-Shaped or Fusiform Cells. This stratum of the postcentral cortex is not distinctive. It contains elements which resemble those of the corresponding layer in other areas of the cortex.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE POSTCENTRAL AREA. *The Zonal Layer.* This layer is poorly developed; its indistinctness serves as one of the distinguishing characters between the postcentral and precentral areas. It consists mainly of fibers with marked varicosities and of fine caliber. Coarse medullated fibers are present but are few in number.

The Supraradiary Layer. This stratum is equal in depth and similar in character to the corresponding zone in the precentral cortex. There is, however, some difference in the degree of fiber development, the area being less abundantly supplied in this respect.

The Layer of Baillarger. This stratum is a dense and broad band visible to the unaided eye and composed of small interlacing fibers passing in all directions, among which are distributed a number of horizontally directed fibers of medium size.

The Layer of Radiations--Radiary Zone. This stratum affords the chief opportunities of fiber differentiation between the postcentral cortex and adjacent areas. The radiary fasciculi of projection fibers are much attenuated. The plexus of association fibers and collaterals is much less dense than in the precentral area. In the radiations of Meynert two or three large sized fibers constitute the main support of each fasciculus. The fibers of medium size are much less numerous in these bundles than is the case in the precentral area. The interradiary association plexus is composed of finer fibers than found in other sensory areas, such as the visual and auditory centers.

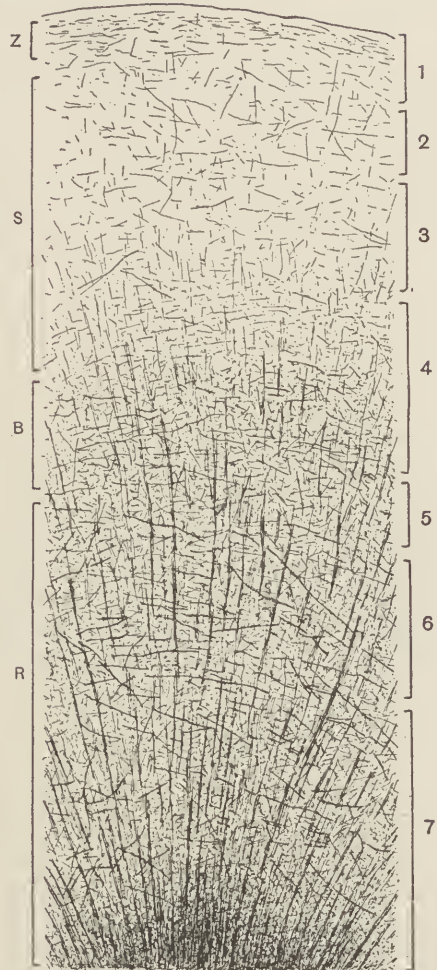


FIG. 529.—Stratigraphic analysis of the fibers in the postcentral or somesthetic sensory area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

SUMMARY OF THE CHIEF STRATIGRAPHIC FEATURES OF THE POSTCENTRAL CORTEX. The chief distinguishing histological features of the postcentral cortex are:

1. The layer of external large pyramidal cells in which the soma of the neurone is considerably larger than that of the corresponding stratum in the precentral area.
2. The pronounced development of the layer of stellate cells in contrast to the relative indefiniteness of this layer in the precentral area.
3. The appearance of the large isolated pyramidal cells in contrast to the clustered pyriform cells of Betz in the precentral area.
4. The feeble development of the zonal layer.
5. The depth and prominence of the layer of Baillarger.
6. The smaller size and more open character of the radiary fasciculi and interradiary plexus.

THE FUNCTIONAL SIGNIFICANCE OF THE POSTCENTRAL AREA. Early conceptions of the function of the postcentral area attributed to it motor activities similar to those of the precentral convolution. More exact experimental differentiation, particularly by means of monopolar electrical stimulation, demonstrated the fact that the postcentral gyrus does not give rise to motor responses. The striking differences in its histological character are further evidence that its function is dissimilar to that of the motor area. The fact that the chief constituents of the somesthetic pathway may be traced from their last relay in the thalamus to this region of the cortex speaks in a positive manner for the sensory character of this area. Impulses of general body sensation passing inward toward the brain over the sensory pathway after the several relays in the spinal cord, medulla and thalamus, eventually reach the postcentral area and make their first definite entrance into the realm of consciousness. The impulses here become conscious impressions concerned in some type of body sensibility. The impression may be a muscle, a joint or a tendon sensation, or again a sensation dependent upon stimulation of the skin and its appendages. In all probability these conscious impressions upon reaching the postcentral area have little definite association. They are, as it were, crude sensations without the attendant values arising from more complex association. They are indiscriminate and non-critical. Were they to remain in the postcentral area and acquire no further elaboration by means of association with other sensory impressions, it is likely that body sensation would be of little service in the higher discriminative and critical processes of sensibility. An impression reaching and remaining in the postcentral area would have no association with similar past impressions, would lack correlation with dissimilar impressions, would be without significance as to the part of the body in which the impression arose, and would exist as a diffuse, undifferentiated sensation. The postcentral area, therefore, may be regarded as the region of the brain which serves as the primary receiving station of all somesthetic impulses which enter into consciousness. It is the threshold over which all somesthetic impressions pass without regard to their character or purpose, a general assembling area of body

sensations without reference to their classification or distinction. In this sense it is the primary sensory region of the brain in which somesthetic sensibility makes its first appearance in consciousness.

Somesthetic sensibility, according to the extensive investigations of Head, depends upon seven different streams of sensory impulses which pass from the thalamus to the cerebral cortex. These are:

1. The tactile stream, which contains impulses produced by every form of contact both superficial and deep. These impulses are graduated from the lightest touch to the heaviest pressure and include the effects of contact with rough objects on the surface of the skin stimulating the hairs, and also all manipulations which cause tingling and itching.

2. The pain stream, in the main concerned with the affective activities of the thalamus, also to a certain extent participates in the cognitive activities of the cortex. Painful and uncomfortable stimuli appeal mainly to the thalamic center, but they have a representation in the cortex in the grading or recognition of differences in intensity and localization of pain. In this activity the postcentral area is involved.

3. The thermal stream for different degrees of heat.

4. The thermal stream for different degrees of cold.

The crude sensations of heat and cold depend upon the affective activities of the thalamus, but the critical sensation of heat and cold by means of which differences in degrees of temperature are recognized is an activity of the postcentral area.

5. The stream of postural relation, or what may be termed *arthro-kinetic sensibility*, by means of which awareness is obtained for different degrees of movements in the joints of the body.

6. The stream of two-point recognition on the surface of the skin.

7. The stream of impulses which lead to recognition of local areas in the body which come under stimulation.

These seven streams of somesthetic sensation flow into the postcentral area. Here they have their primary interpretation. Subsequently they receive further association and take on more comprehensive significance as elements in body consciousness.

Syndrome of the Postcentral Area. Although it is yet too early to delineate the syndrome resulting from disease of the postcentral area with an exactness approaching the recognized syndrome of the precentral area, yet certain clinical features are indicative of lesions in the somesthetosensory region. These clinical indications are based on recent work by Head, who had the opportunity to study a number of gunshot wounds affecting this area of the brain.

When the postcentral convolution is injured or defective, the patient manifests some loss of awareness in one or more of the several streams of sensory impulses passing to the sensory area. Postural sense, localization sensibility, two-point sensibility, differentiation in degrees of cold and degrees of heat, and tactile sense, may all suffer a complete loss or diminution. As a rule this loss is irregular. Postural sense may be most affected in

one finger, tactile sense in the next finger, and heat and cold in the third finger. The irregular distribution and marked variations in these defects constitute an essential clinical feature in the recognition of lesions involving the postcentral area.

An attendant symptom in the syndrome of the postcentral convolution is a marked hypotonia in the affected parts, which appears to be due to a disturbance in postural sensibility.

The chief clinical indications of lesions in the postcentral area are: (1) Irregular and variable impairments in the tactile, the heat and cold, the postural, the discriminative and the localizing elements of sensibility; (2) an accompanying hypotonia of the affected parts of the body.

The Intermediate Postcentral Area (*Somestheto-Psychic Area*). **BOUNDARIES AND DISTRIBUTION.** Adjacent to the postcentral area is a type of cortex closely resembling that in the somestheto-sensory zone. At its cephalic boundary it merges without sharp line of demarcation with that of the typical postcentral field. On the mesial surface of the hemisphere, it occupies the caudal portion of the paracentral lobule and is limited below by the calloso-marginal fissure. In this manner, it forms a peripheral zone which embraces the mesial portion of the postcentral area. Its caudal limit is the vertical limb of the intraparietal fissure, while its ventral extremity reaches a point in close proximity to the fissure of Sylvius. Its average depth is 1.5 to 2 cm., its narrowest zone being at the junction of its middle and lower thirds.

STRATIGRAPHICAL DESCRIPTION OF THE CELLS IN THE INTERMEDIATE POSTCENTRAL AREA. The *plexiform layer*, together with the *layer of small pyramidal cells* and the *layer of medium-sized pyramidal cells*, correspond closely in depth and general character to those of the postcentral area.

The *layers of external and internal large pyramidal cells* show some important changes in the character of the constituent elements. The larger cells noted in the postcentral area are not represented in the intermediate postcentral area, while there is a reduction in the size of the other cellular elements entering into these zones. In this latter respect, the intermediate postcentral cortex assumes characters which distinguish the parietal cortex. The general similarity of the postcentral and intermediate postcentral areas, however, is easily recognized.

The *layer of stellate cells* in the intermediate postcentral area has considerably greater depth than in the postcentral area, but is not so dense nor does it contain relatively so many cells.

The *layer of spindle-shaped or fusiform cells* presents little which is distinctive and in general corresponds to this layer in other parts of the cortex.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE INTERMEDIATE POSTCENTRAL AREA. The *zonal layer* is feebly developed and gradually becomes less prominent, due to the attenuation and final disappearance of the large medullated fibers.

The *supraradiary layer* also presents a gradual decrease in its fiber representation.

The *layer of Baillarger*, although it retains its relative position and depth, is less dense and stains less deeply due to the absence of large fibers.

The *radiary layer* is less prominent than in the postcentral area due to the absence of coarse medullated fibers. The *interradiary plexus* is made up of fibers of the same calibre and hence is less conspicuous. The large fibers are absent, which gives an added reason for the inferior representation of the *interradiary plexus*.

SUMMARY OF THE CHIEF STRATIGRAPHIC FEATURES OF THE INTERMEDIATE POSTCENTRAL AREA. This field of cortex is definitely of the postcentral type, but seems to bear the same relation to it as does the intermediate precentral to the precentral area. It is a feebly developed replica of the primary sensory area. Most of the characteristic features which identify the postcentral area are present in the intermediate postcentral area.

1. The large pyramidal elements in both the external and internal large pyramidal layers are wanting.

2. The layer of stellate cells has greater depth than in the postcentral area. Its cellular representation, however, is less prominent.

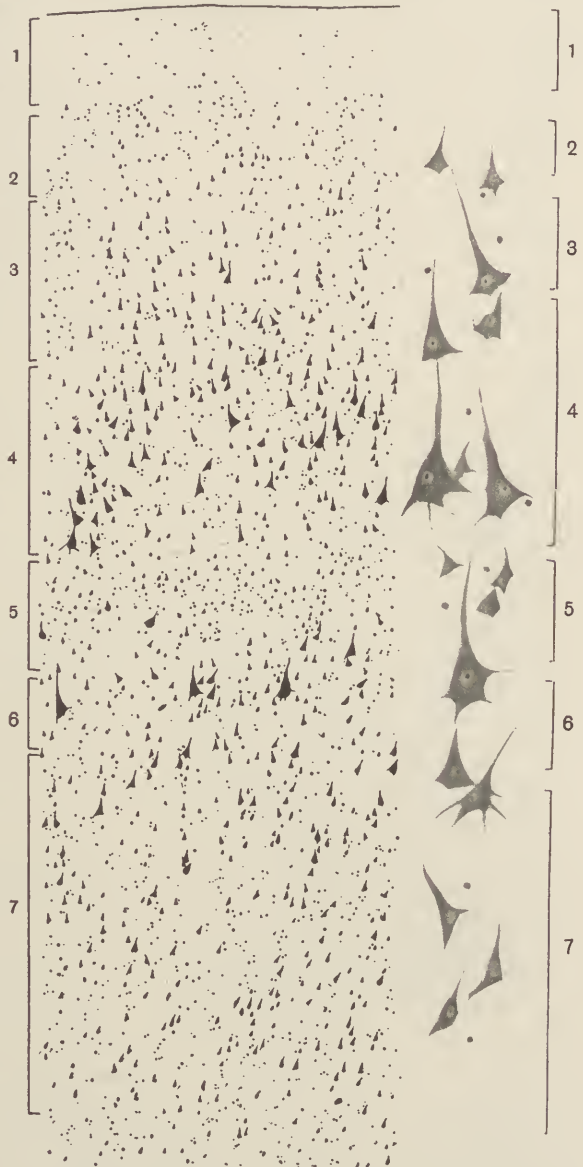


FIG. 530.—Stratigraphic analysis of the cells in the intermediate postcentral or somestheto-psychic area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

FUNCTIONAL SIGNIFICANCE OF THE INTERMEDIATE POSTCENTRAL AREA. This zone of cortex which holds an intimate relation to the postcentral area,

serves in the capacity of an elaborating field in the consciousness of body sensibility. The several streams of sensory impulses received by the primary sensory area require further association in order that they may attain their full usefulness. Provision for such association is made in the intermediate postcentral area, a region in which combinations take place between the various fundamental qualitates of body sensation. These combinations take



FIG. 531.—Stratigraphic analysis of the fibers in the intermediate post-central or somestheto-psychic area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

their character from the more or less lasting imprint which each sensory impulse makes. They are discretely registered in the brain in relation to previous impulses of the same kind. This process may be likened to cataloguing—a type of cerebral activity which selects and files in proper relation to each other sensory impression impulses having the same general character. In addition to this memory registration each impulse is provided with the opportunity to relate itself to other similar impulses with regard to its intensity; whether, for example, it is stronger or weaker than the similar impulses which have gone before. The impulse is also given opportunity to be compared to or combined with dissimilar sensory impressions. This process of establishing relativity seems to be one of the essential functions of the intermediate postcentral area.

In substance, therefore, the intermediate postcentral area serves for the memory registration and apperception of impulse intensity and relativity. It also provides for the combination of similar and dissimilar types of body sensibility to form the most effective sensory syntheses.

An example of this sensory elaboration will serve to illustrate the possible course of the sensory impulse in

the intermediate postcentral area. With the eyes closed the finger is submerged in a bowl of cold water. Consciousness of a change in environment of this part is at once aroused. The evaluation of the character of this change depends upon further elaboration of this crude sensory awareness. The tactile impulse due to the contact of the water with the skin would not in itself be sufficient to produce recognition of the character of the

stimulus. The impulse of coldness associated with the tactile impression gives information concerning the temperature of the substance with which contact is made. An impulse of muscle sensation is introduced by the fact that the finger is pressed progressively further into the stimulating medium without requiring much muscular effort to overcome the resistance of the water. The consistency of the medium is thus determined. Submerging the hand in water occasions less resistance to muscular effort than submerging it in oil or some thicker mixture. Finally, the stimulation of the hairs on the surface of the skin by the degree of viscosity inherent in water gives the information that the stimulating medium is water and not oil or some more viscid substance.

Another example illustrates the combination of somesthetic impulses necessary to the recognition of objects by palpation. A wooden cube measuring one inch, and weighing one ounce, is placed in the palm of the hand of the subject, who is instructed to grasp and palpate it. Under normal conditions it is possible to identify the nature of this object without looking at it. This sensory act implies a recognition of the form, size, weight, consistency and temperature of the object. Upon analysis it is clear that such a somesthetic conception depends upon the blending of sensory impressions arising from tactile impulses caused by the contact of the object with the skin covering the palm of the hand, from pressure of the object upon the skin and deeper tissues, and from tactile impressions of a critical nature giving information as to the relative smoothness or roughness of the surfaces. Temperature sensibility also plays some part in that the surface of wood is less cold than that of metal or glass, and not so warm, for example, as cloth fabrics. Tactile and temperature sensibility thus play the leading rôle in constructing the conception of the consistency of the object. The weight of the object is recognized by the pressure upon the skin and subcutaneous tissues. The size is recognized by two-point sensibility which indicates the distance between the edges of the cube in contact with the skin, and, even more important, by muscle and joint sensibility which makes possible the recognition of the distance between the edges of the cube when palpated between the thumb and fingers or between the fingers and palm. Form is recognized by tactile and muscle-joint sensibility which permits the identification of the surface contour. All of the primary somesthetic impressions must be properly combined in order to produce the conception of the wooden cube placed in the hand. This identification would be impossible were it not for the permanent record within the brain of similar previous conceptions which serve as comparisons and thus constitute the criteria for a sensory judgment.

The ability to recognize objects by palpation is called *stereognosis* (*stereo*, form; *gnosis*, knowledge). This is a special form of body feeling knowledge (*somesthetognosis*). The area specially concerned in stereognosis is usually described as occupying the upper portion of the intermediate post-central area which is bounded below by the horizontal limb of the inter-parietal sulcus and in front by the dorsal division of the ascending limb of

this fissure. The recognition of different weights belongs in the same group and is known as *barognosis* (*baro*, weight; *gnosis*, knowledge). Similarly, the recognition of different positions of the limbs and the component parts of each limb in relation to each other is known as *acrognesis* (*acro*, limb; *gnosis*, knowledge), while the identification of areas of the body stimulated by touch or compression is known as *topognosis* (*topo*, place; *gnosis* knowledge). Unquestionably, other syntheses of sensory impressions exist as special forms of somesthetognosis.

Syndromes of the Intermediate Postcentral Area. As the result of lesions limited to the intermediate postcentral area the most common defect is a failure of stereognosis. The patient is no longer able to identify by means of palpation the form, size, consistency or weight of objects placed in the hand. This condition is known as *astereognosis*. The pure form of this defect exists only when the actual form-knowledge of the object is defective, although the patient is able to perceive the individual primary impressions out of which he normally constructs his conception by means of palpation. In other words, he fails to combine the sensory factors necessary to form-knowledge. Although it is rare for lesions to limit themselves strictly to the intermediate postcentral region, enough clinical material has been available to warrant this interpretation of pathological changes affecting the upper portion of the intermediate postcentral area.

In addition to this astereognostic defect in somesthetic sensibility, patients suffering from disease or injury involving the intermediate postcentral area frequently lose limb-knowledge and weight-recognition. The test to demonstrate the former defect is conducted as follows: The patient is blindfolded. The affected arm is placed in a certain posture abducted at a considerable distance from the body and the thumb is put in an extended position. He is instructed to grasp the thumb of the affected hand between the normal thumb and index finger. In attempting to carry out this instruction he gropes about showing that he has no realization of the position of the affected limb. He is able to carry out the instruction only when he places the sound hand upon the shoulder and finds his way by this manœuvre to the thumb. This lack of limb-knowledge is known as *acragnosis*. If tested by weights placed upon the immobilized hand, these patients frequently show a marked deficiency in weight perception. Even when permitted to move the hand and fingers in order to bring the muscle and joint sensibility more into play, it is still impossible for them to arrive at a proper recognition of the weight of objects. This condition is known as *baragnosis*.

The chief clinical feature constituting the syndrome of the intermediate postcentral area is astereognosis. Acragnosis and baragnosis may be attendant disturbances. Not infrequently these defects in somesthetic knowledge are attended by a greater or less degree of hypotonia.

The Calcarine or Visuo-Sensory Area. The visuo-sensory or calcarine area consists of those parts of the cerebral cortex which form the boundary of the calcarine fissure and in which is found a deep striation known as the *line of Gennari*. This line is recognized by the unaided eye in sections of the

fresh brain. It is situated about midway between the surface of the cortex and the medullary substance.

LANDMARKS OF THE VISUO-SENSORY AREA. The important landmark in relation with the visuo-sensory cortex is the calcarine fissure which consists of an anterior or stem division, the *fissura calcarina anterior*, and a posterior division, the *fissura calcarina posterior*. The stem of the fissure is situated cranially to the junction of the parieto-occipital and calcarine fissures. This portion of the calcarine sulcus is a complete fissure and is much deeper than its posterior portion. A deep annectant convolution, the gyrus cunei, separates the stem from the parieto-occipital fissure. Another such annectant gyrus intervenes between the stem and the caudal portion of the calcarine fissure. It serves to connect the cuneus with the lingual lobule and is known as the *anterior cuneo-lingual gyrus*.

The posterior division of the calcarine fissure is more shallow and shorter than the stem portion. Its average length is 35 to 40 mm. At its caudal extremity it is divided into two segments by a deep annectant gyrus which connects the cuneus with the caudal portion of the gyrus lingualis. This is the *posterior cuneo-lingual gyrus*. The cuneo-lingual annectant reaches the surface in a number of cases in such a way as to subtend the caudal forked extremity of the calcarine fissure, which under these circumstances is known as the *fissura retrocalcarina*. The retrocalcarine fissure is vertical in its direction and lies close to the occipital pole of the hemisphere. In the majority of cases, it forms a direct connection with the caudal division of the calcarine fissure and is confined to the mesial surface. In some instances, however, it is visible upon the convexity of the occipital pole.

BOUNDARIES AND DISTRIBUTION OF THE VISUO-SENSORY AREA. The visuo-sensory cortex, containing the line of Gennari, limits itself to the confines of the calcarine fissure. In the majority of instances the visuo-sensory type of cortex does not reach forward to the cranial extremity of the fissure, but falls short of this by 5 to 10 mm. The lower lip of the fissure contains the visuo-sensory cortex further forward than does the upper lip; in fact, the visuo-sensory cortex stops short at the junction of the calcarine and parieto-occipital fissures. From the junction of the calcarine and parieto-occipital fissures as far caudal as and surrounding the forked extremity of the calcarine sulcus, the visuo-sensory type of cortex is present in both lips of the fissure. It reaches into and forms the floor of the calcarine sulcus; it extends over the upper wall and the lower walls, covering the anterior and posterior cuneo-lingual annectant gyri, and spreading out upon the mesial surface for a distance of about 1 cm. upon the cuneus and lobus lingualis. A small fissure, the *cuneal sulcus*, runs parallel to the posterior division of the calcarine fissure in the cuneus. This in a general sense, when present, forms the dorsal boundary of the visuo-sensory area. The cuneal sulcus, however, is inconstant and therefore not a reliable landmark. The relation of the visuo-sensory area to the retrocalcarine fissure is such that this sulcus is entirely surrounded by this type of cortex. A small portion of the visuo-sensory area may appear at the occipital pole. In such instances the boundaries of the

region are determined by several small semilunar fissures whose general direction is vertical. These are the *semilunar fissures of Bolton*.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE VISUO-SENSORY AREA. *The plexiform layer* is narrower than in other cortical areas, probably due to the small number of medium-sized and large pyramidal cells in the

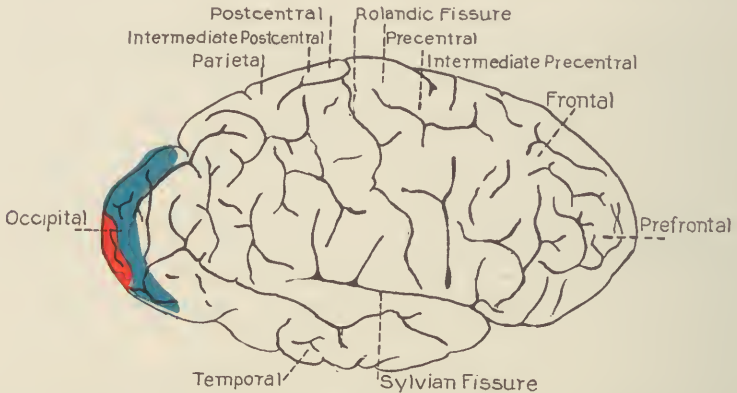


FIG. 532.—Cerebral cortex—lateral surface. Red indicates visuo-sensory area. Blue indicates visuo-psychie area.

subjacent strata. A type of cell characteristic of this region has been described by Cajal. These cells have a horizontal direction and probably act as the means of bringing the large association fibers into relation with the pyramidal cells of neighboring convolutions.

The Layer of Small Pyramidal Cells. This cellular stratum is without

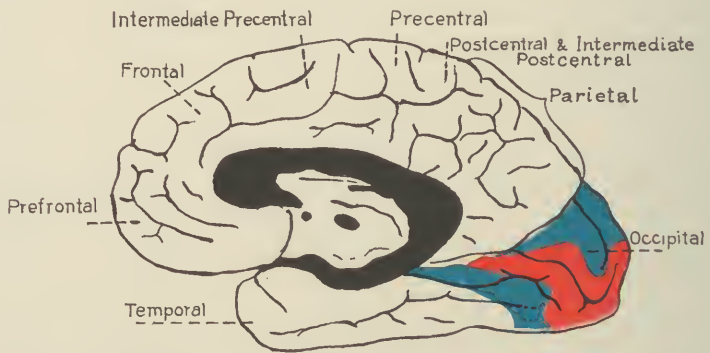


FIG. 533.—Cerebral cortex—mesial surface. Red indicates visuo-sensory area. Blue indicates visuo-psychie area.

special features with the exception of the compact arrangement of its constituent cells.

The Layer of Medium-Sized Pyramidal Cells. This stratum corresponds in the main with the same layer in other areas. Occasionally large pyramidal cells are observed at this level.

The Layer of External Large Pyramidal Cells. This stratum is one of the distinctive features of the visuo-sensory cortex. It is broad, measuring .3 mm., and the large pyramidal cells which occupy a corresponding position in other cortical regions are almost entirely absent. Their place is taken by large stellate cells, interspersed among which are smaller elements resembling those of the subjacent stellate layer. The large stellate cells lie mainly in the outer zone of this stratum.

They are triangular or quadrilateral in form and have three to four dendrites which follow no definite direction. Their chromophilic bodies are irregular, scattered clumps, and their mean diameter is 25 micra. They are rather meagerly scattered throughout this layer, occupying a zone which is coincident with the line of Gennari.

The Layer of Stellate Cells. This stratum is considerably narrower than elsewhere, measuring about 1.7 mm. The cells are small, fusiform, triangular bodies which correspond to those in other areas.

The Layer of Internal Large Pyramidal Cells. This layer contains two types of cells. First, the giant pyramidal cells or solitary cells of Meynert which constitute an important distinguishing feature of the visuo-sensory area. They form a single

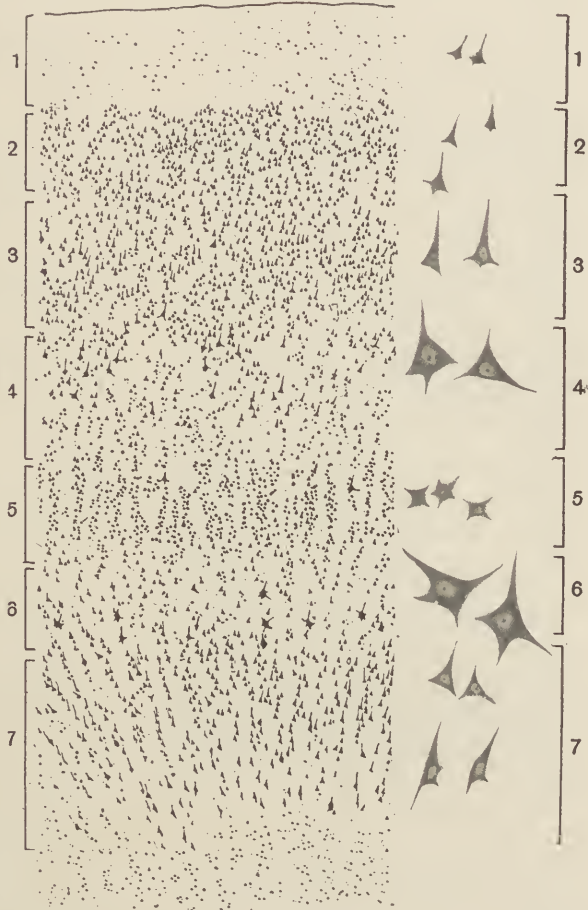


FIG. 534.—Stratigraphic analysis of the cells in the calcarine or visuo-sensory area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells, cells of Meynert. 7. Layer of fusiform cells.

row separated by a considerable distance from each other. They are triangular in shape with their apices directed toward the surface. Their bodies measure 25 to 30 micra. The apical dendrite extends to the plexiform layer. Scattered among these large pyramidal elements are cells of the pyramidal type, but smaller. These cells have a long ascending axone which extends into the plexiform layer.

The Layer of Fusiform Cells. This layer is of considerable depth and contains fusiform and triangular cells, among which are scattered medium-sized pyramidal elements. Their dendrites pass in a horizontal direction and their large number gives this layer a compact appearance.

THE STRATIGRAPHICAL DESCRIPTION OF THE FIBERS IN THE VISUO-SENSORY AREA. *The Zonal Layer.* This stratum is relatively well developed, but is not so prominent as in the precentral cortex. Its internal border lacks sharp definition. The chief constituents of the zonal layer are varicose fibers among which are interspersed some large medullated axones.

The Supraradiary Layer. This consists chiefly of a dense plexus of fibers of delicate caliber with occasional axones of a coarser variety representing the *fibers of Martinotti*, which extend up to the zonal layer.

The Layer of Baillarger. This stratum is the most conspicuous feature of the visuo-sensory area. As compared with other areas of the cortex, the line of Baillarger is several times deeper and constitutes the feature in this area which may be detected by the unaided eye. It is so prominent that it has received the special name of *line of Gennari*.

The Radiary Layer. This stratum consists of the usual radiary fasciculi and interradiary plexus. The interradiary plexus as well as the association fibers are poorly represented, so that the region has a pallid appearance. This gives greater definition to the line of Gennari. The radiations of Meynert are similar to the corresponding layer in other areas with the exception that



FIG. 535.—Stratigraphic analysis of the fibers in the calcarine or visuo-sensory area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. G—layer of Gennari (Baillarger). R—Radiary layer. The numerals indicate positions corresponding to the cellular layers of the cortex.

they contain more coarse medullated fibers than is the case in the post-central or intermediate postcentral area, and approach the condition of the precentral area in this respect.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES OF THE VISUO-SENSORY AREA. The chief distinguishing features of the visuo-sensory area are:

1. The unique layer of large stellate cells replacing the external layer of large pyramidal cells.
2. The presence of the solitary pyramidal cells of Meynert.
3. The appearance of the line of Gennari.

Functional Significance of the Visuo-Sensory Area. There is a functional parallelism between the visuo-sensory and the somestheto-sensory areas. The visuo-sensory area, like its somesthetic counterpart, is a primary cortical receiving center. Visual sensibility depends upon the combination of several different types of visual perceptions. The knowledge obtained by means of vision comprises impressions of color, size and dimension, form, motion, distance and projection, illumination and transparency. Objects are recognized by means of psychic processes resulting in syntheses of these simple visual impressions. Each of the simple forms of visual impression is comparable to the simpler forms of somesthetic sensibility. When the visuo-sensory or calcarine area is destroyed, these impressions are no longer perceived and a visual anesthesia, or blindness, results.

A number of fibers arise in the calcarine area and join the projection system of the cerebral cortex. They pass outward in the optic radiation, enter the retrolenticular portion of the internal capsule, and eventually terminate in the midbrain. The exact destination of these fibers is not entirely certain at present. It is generally conceded that the axones establish connections with the nucleus oculomotorius. Some of the fibers end in the superior colliculus and by means of the tecto-bulbar tract may afford communication with the nucleus abducens. Several functions have been ascribed to this efferent visual tract. By some, it is regarded as a corticifugal control of reflexes governing the size of the pupil in response to light. Others believe that this connection serves the purposes of attentional control of the oculomotor movements necessary to gaze.

Lesions which destroy both calcarine areas, thus causing total blindness, also abolish ocular convergence. It seems fair to presume that the cortico-mesencephalic connection serves as a means of adjusting the ocular muscles to the requirements of visual attention. Patients who are not able to perform oculo-gyric movements to the right or left, above or below, when instructed to look in these directions, are often capable of holding their eyes fixed upon an object although the head is rotated to the right or left, upward or downward. This act implies the ability to hold the object

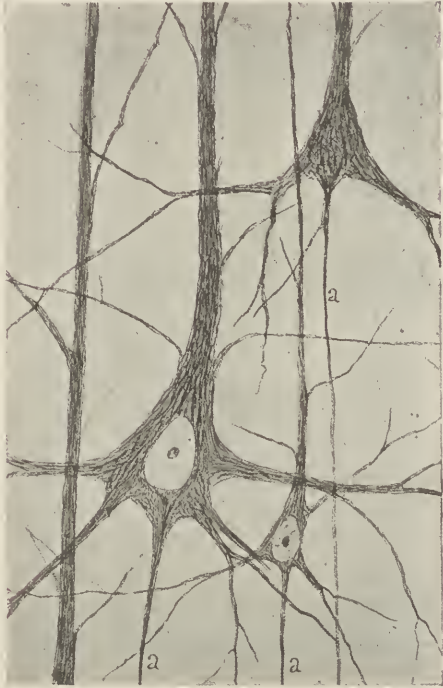


FIG. 536.—Neurofibrils of large and medium-sized pyramidal cells in the visual cortex of man. Silver nitrate reduction. *a*—Axis cylinder. (Cajal.)

in vision by means of the ocular muscles, although it is impossible volitionally to turn the eyes in any direction. In this sense a *paralysis of direction of gaze* may be distinguished from a *paralysis of fixation of gaze*. The fixation depends upon the occipital cortex; the direction depends upon the motor cortex.

The Syndrome of the Visuo-Sensory Area. The impairment or destruction of the calcarine area of one side produces a defect analogous to the sensory disturbances due to lesions in the somesthetic area. A lesion destroying the postcentral region on the right side gives rise to sensory defects on the left side of the body, that is, *hemianesthesia*. A lesion of the calcarine area on the right side causes a left hemianoptic (loss of vision on one side) defect, that is, blindness in the visual field on the left side of the body. The hemianesthesia and hemianopsia, although analogous, are not entirely similar in their mode of production. The hemianesthesia depends upon a disturbance limited to one side of the body. The hemianopsia depends upon a functional disturbance in both eyes. As sensory end-organs, eyes possessing binocular vision act in such a way that one half of each retina serves for vision on the same side, while the other half receives visual stimuli on the opposite side. In other words, visual stimuli coming from the right are simultaneously received by the left half of the left eye and the left half of the right eye, while visual stimuli from the left are simultaneously received by the right half of the right eye and the right half of the left eye. In order that objects may be clearly perceived by this simultaneous reception of stimuli in the two retinæ, there are spots in the right retina corresponding with similar spots in the left retina. These are known as *identical or homonymous points*. In this sense each retina comprises a series of homonymous points which cover the two major fields of vision; that is, the right and the left visual field. In the right and left retinæ there are homonymous points for the right visual field, and similar points for the left visual field. The homonymous retinal points necessary to cover the right visual field lie in the left half of the right retina and the left half of the left retina. Their combined normal activity, making vision to the right possible, constitutes *right homonymous hemiopsia*. Their combined normal action which makes vision to the left possible constitutes *left homonymous hemiopsia*. Right homonymous hemiopsia depends upon normal activity of the left visuo-sensory area; left homonymous hemiopsia depends upon normal activity of the right visuo-sensory area. A destruction of the left calcarine (visuo-sensory) area results in a *right homonymous hemianopsia*. Under these circumstances the patient is blind for everything upon the right side while he retains normal vision in his left visual field.

Homonymous hemianopsia is a sensory disturbance which in its general nature is parallel to hemianesthesia. Its mechanism differs in the fact that both eyes are necessary to complete visual perception to the right or to the left.

Defects in primary visual perception may show partial involvement of the homonymous visual fields. The superior quadrants of the retina are

represented in the upper lip of the calcarine fissure. The lower quadrants have their centers in the lower lip of the calcarine fissure. The cortical area for central vision, known as the *macular center*, is situated at the pole of either occipital lobe. Hemianoptic defects in vision may be *quadrantic*; that is, affect the upper or lower quadrants of either visual field. Such disturbances result in *inferior quadrantic hemianopsia* in which the patient is unable to see objects below the level of the eyes, but can see well above this level; or in *superior quadrantic hemianopsia* in which he is unable to distinguish objects above although vision below the level of his eyes is retained. One quadrant in either visual field may be impaired, in which event the visual defect is termed *superior homonymous hemianopsia* or *inferior homonymous hemianopsia*. Many degrees and variations of the hemianoptic defect may occur dependent upon the extent to which the quadrantic representation of the visual fields in the calcarine area is involved.

In summary, the disturbances due to involvement of the calcarine or visuo-sensory area are:

1. Lesion of the right side—left homonymous hemianopsia.
2. Lesion of the left side—right homonymous hemianopsia.
3. Lesion in the upper lip of the calcarine fissure—*inferior quadrantic hemianopsia*.
4. Lesion in the lower lip of the calcarine fissure—*superior quadrantic hemianopsia*.
5. Lesion in both calcarine areas—complete loss of vision.

The Occipital or Visuo-Psychic Area. The visuo-psychic area adjoins and surrounds the visuo-sensory area. It bears the same relation to the calcarine area that the intermediate postcentral or somestheto-psychic area bears to the somestheto-sensory area.

BOUNDARIES AND DISTRIBUTION OF THE VISUO-PSYCHIC AREA. This type of cortex has distinctive characters which identify it on both the mesial and lateral surfaces of the hemisphere. Upon the mesial surface, it is situated between the upper border of the visuo-sensory area and the occipito-parietal fissure. It is situated beneath the ventral margin of the calcarine area and extends as far ventrally as the collateral fissure, thus including the greater portion of the lingual lobule. It reaches as far forward as the isthmus limbici, and covers the deep cuneo-limbic annectant gyrus at the junction of the parieto-occipital and calcarine fissures. On the lateral surface it surrounds the caudal pole of the visuo-sensory area and extends as far forward as the line determined by the junction of the superior and inferior occipital sulci.

These boundaries are not constant. In general the visuo-psychic area comprises a zone of cortex varying from 1.3 to 2 cm. in width, which invests the visuo-sensory area on all sides with the exception of that portion immediately below the anterior division of the calcarine fissure.

STRATIGRAPHIC DESCRIPTION OF THE CELLS OF THE VISUO-PSYCHIC AREA. The *plexiform layer* and the *layer of small and medium-sized pyramidal cells* are appreciably deeper than in the calcarine area. The cells are uniformly larger and, being less numerous, they stand out more prominently.

The layer of external large pyramidal cells shows important differences.

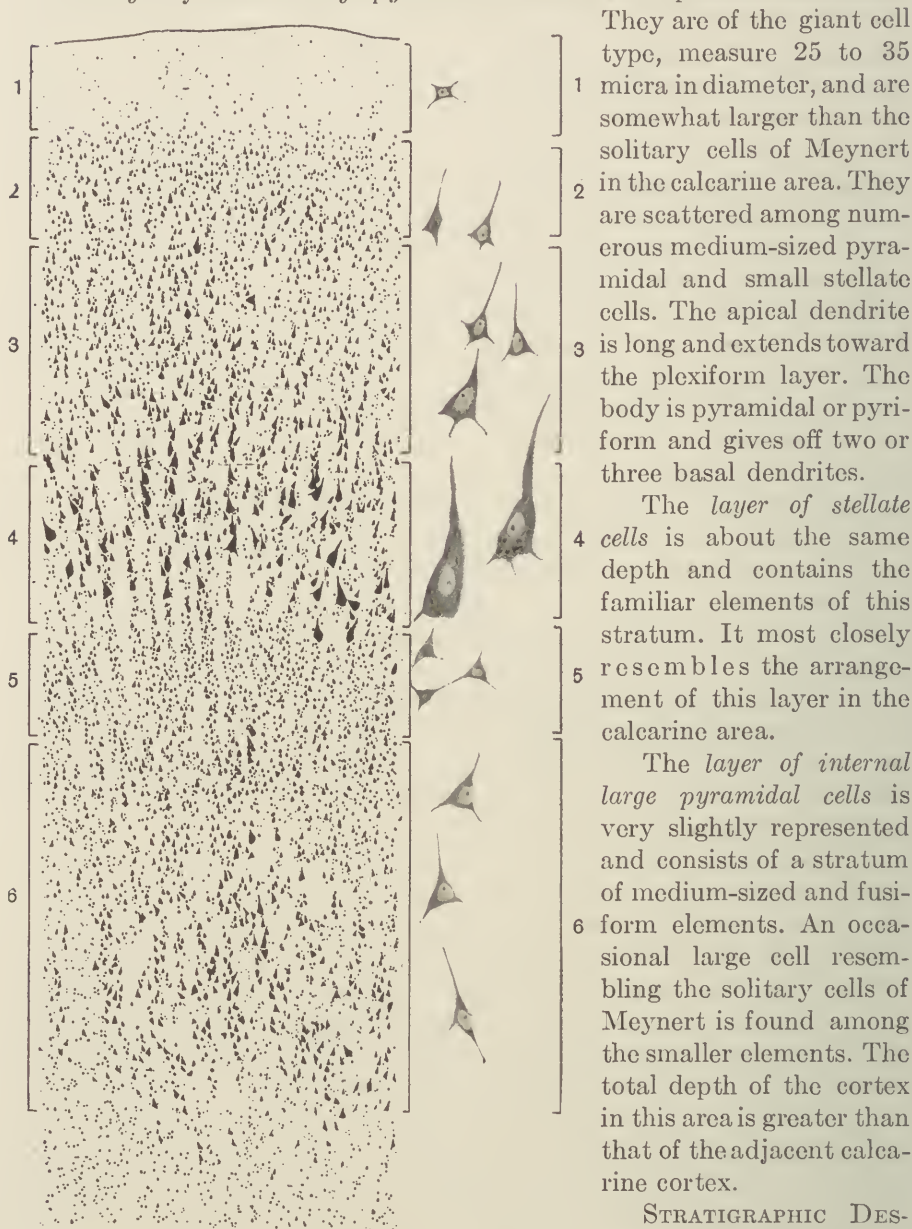


FIG. 537.—Stratigraphic analysis of the cells in the occipital or visuo-psychic area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of fusiform cells.

They are of the giant cell type, measure 25 to 35 micra in diameter, and are somewhat larger than the solitary cells of Meynert in the calcarine area. They are scattered among numerous medium-sized pyramidal and small stellate cells. The apical dendrite is long and extends toward the plexiform layer. The body is pyramidal or pyriform and gives off two or three basal dendrites.

The layer of stellate cells is about the same depth and contains the familiar elements of this stratum. It most closely resembles the arrangement of this layer in the calcarine area.

The layer of internal large pyramidal cells is very slightly represented and consists of a stratum of medium-sized and fusiform elements. An occasional large cell resembling the solitary cells of Meynert is found among the smaller elements. The total depth of the cortex in this area is greater than that of the adjacent calcarine cortex.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS OF THE VISUO-PSYCHIC AREA. *The Zonal Layer.* This stratum is well developed and more pronounced than in the calcarine region. Its lower margin is sharply defined. Coarse varicose fibers are present in large numbers. Occasional large medullated fibers are also found.

The Supraradiary Layer. This stratum consists of a dense network of fine fibers composed of short irregularly placed axones. The fibers are of medium size and extend in all directions. Among them a certain number of fibers of Martinotti are found. This layer has a greater representation of fibers in it than has the calcarine area or the adjacent temporal or parietal cortex.

The Layer of Baillarger. Baillarger's line is one of the important features of this region. Its depth is greater than that in the calcarine area but less sharply defined. It tends to spread out into the adjoining layers and its margins are in consequence blurred. Although less well defined, the line of Gennari may be as distinctly recognized as in the visuo-sensory area.

The Layer of Radiations—Radiary Layer. The radiations of Meynert contain many fine wavy fibers and a few coarser ones. The interradiary plexus and association fibers consist of a great wealth of axones which may be regarded as the most distinctive feature of this type of cortex. In caliber, the large association fibers are of greater size than those in the corresponding zone of the calcarine cortex.

SUMMARY OF THE CHIEF STRATIGRAPHIC FEATURES OF THE VISUO-PSYCHIC AREA. In general, the visuo-psychic area corresponds closely to the visuo-sensory area. It differs principally:

1. In the marked scarcity of the solitary cells of Meynert, which constitute such important elements in the layer of internal large pyramidal cells of the calcarine area.

2. In the width and lack of marginal definition in the line of Gennari.

3. In the density and depth of the interradiary plexus and association

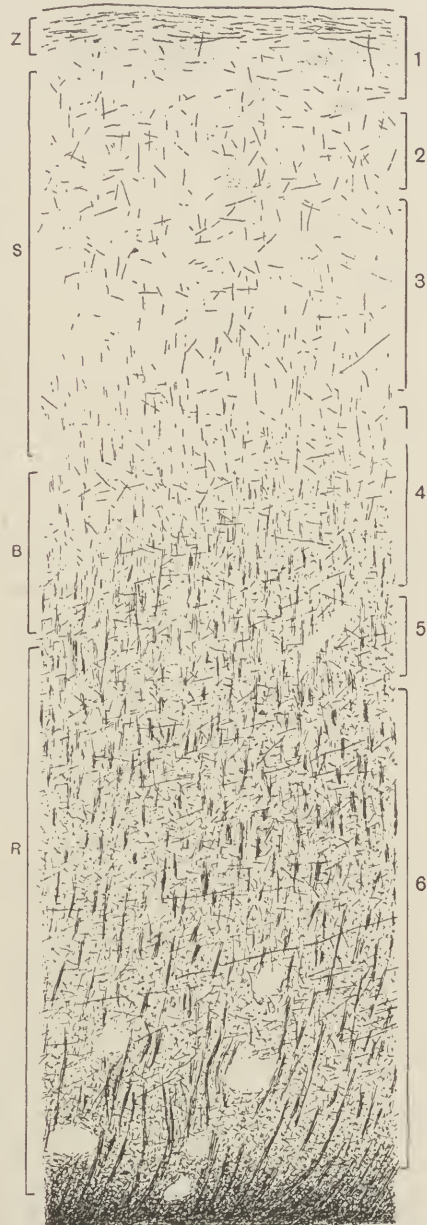


FIG. 538.—Stratigraphic analysis of the fibers in the occipital or visuo-psychic area. (Campbell.)

Z—Zonallayer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the cellular layers of the cortex.

fibers, together with the absence of larger fibers in the radiations of Meynert which belong to the projection system.

FUNCTIONAL SIGNIFICANCE OF THE VISUO-PSYCHIC AREA. Visual knowledge (*visuognosis*) depends upon the combination of the primary visual impressions. These impressions pertain to color, dimensions, form, motion, distance and projection, illumination and transparency. In order to have the proper recognition of an object several or all of these impressions must not only be brought in proper association with each other, but must also be in proper relation with previous visual experiences of the same kind. This association alone is not sufficient for the complete differentiation of objects. The visual synthesis must also be correlated with dissimilar but closely related combinations of visual impressions. The distinction of two objects high in the air, such as a bird and an aeroplane, depends upon the perception of distance and projection which conveys the impression to the mind of the relative size of the two objects. In order that the aeroplane may appear to have the size of the bird it must be much further from the eye. The impression of projection or relative distance in this way becomes essential in the recognition. The forms of the two objects are compared and an attempt made to establish certain contrasting differences and recognize essential similarities. The color of the objects under these circumstances may be negligible in the differentiation. In the process of making a distinction between the two objects the salient difference is found in their motion. Both the bird and the aeroplane are seen to move, but their motion differs in a striking way. The gliding movement through space of the aeroplane distinguishes it from the bird which, in addition to locomotion, produces distinct visual impression as a result of the intrinsic movements of its wings, although at a great distance it may not produce the impression of flying. This process of differentiation requires previous conception of the attributes which make possible the recognition of the bird in the air and similar previous recognition of the aeroplane.

It is evident from this illustration that visual knowledge depends upon a synthesis of primary visual impressions compared and contrasted with previous visual syntheses which have entered into visual experience. These associations constitute the psychic activities of visual function. It is possible that the associations may be partially impaired by defects in or the absence of one or more of the primary visual impressions.

Syndromes of the Visuo-Psychic Area. Several forms of visuo-psychic disturbance have been described under the term *psychic blindness*. In this defect, the lesion in a right-handed individual is most commonly situated in the left visuo-psychic (occipital) area. The patient manifests on disturbance in primary visual impressions, but is highly defective in the synthetic processes necessary to visual knowledge. He identifies objects without recognizing their nature. He sees but does not understand what he sees. He has difficulties in the orientation of objects in space and is inaccurate in judging distances from the body. The form, color, motion or lack of motion in objects assist him little or not at all in identifying their character. Food placed

before him is not recognized as such unless some other type of sensibility, as the sense of smell, is provoked to assist in the identification. He may be able to make his way without accident or injury through crowded streets, but he fails to recognize the nature of objects which he avoids. This condition is known as *psychic blindness*. It is due to the imperfect combination of primary visual impressions which causes a loss in their proper association and interpretation.

Color-blindness, or *dyschromatopsia*, is another form of visuo-psychic disturbance which has been attributed to lesions in the occipital lobe. According to some authorities the disturbance may be a *hemiachromatopsia*, in which case the lesion is confined to the caudal portion of the lingual lobule. It may be that color-blindness is a visuo-sensory rather than a visuo-psychic, disturbance, since it seems to implicate one of the primary visual qualities rather than a visual synthesis. Color blindness due to organic lesion should only be tentatively placed among the visuo-psychic disturbances.

The Transverse Temporal Gyri of Heschl or The Audito-Sensory Area.

BOUNDARIES AND DISTRIBUTION OF THE AUDITO-SENSORY AREA. The temporal lobe which has come to be associated with auditory function, comprises three different types of cortex.

The first type of temporal cortex is concealed from view in the depths of the Sylvian fissure. It covers several transverse gyri which extend across the dorsal surface of the temporal lobe. In order to bring these transverse gyri to view it is necessary to excise the frontal and parietal opercula which conceal the island of Reil. When this part of the hemisphere is removed two or three prominent convolutions are brought to view upon the dorsal surface of the temporal lobe about midway between the temporal pole and the caudal extremity of the Sylvian fissure. These are the *transverse gyri of Heschl*. The audito-sensory portion of the temporal lobe is confined to these gyri. The cephalic boundary of this area is indicated by the transition from the most cephalic of the transverse gyri to the relatively flat surface of the superior temporal convolution. The caudal boundary of this area is less well defined but may be marked by the transition between the most caudal transverse gyrus and the flat concealed surface of the superior temporal convolution. Mesially the transverse gyri of Heschl converge and the audito-sensory cortex ceases in this direction at the point of their final convergence.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE TRANSVERSE TEMPORAL GYRI. *The Plexiform Layer.* This stratum averages about 0.29 mm. in depth, but presents no distinguishing characters either in the cellular constituents or the arrangement of its fibers.

The Layer of Small Pyramidal Cells. The depth of this stratum is 0.2 mm. The cells are very numerous and present a compact appearance.

The Layer of Medium-Sized Pyramidal Cells. This stratum is without sharp line of demarcation from the adjacent layers. It merges with the layer of large pyramidal cells. The number of medium-sized cells, however, is

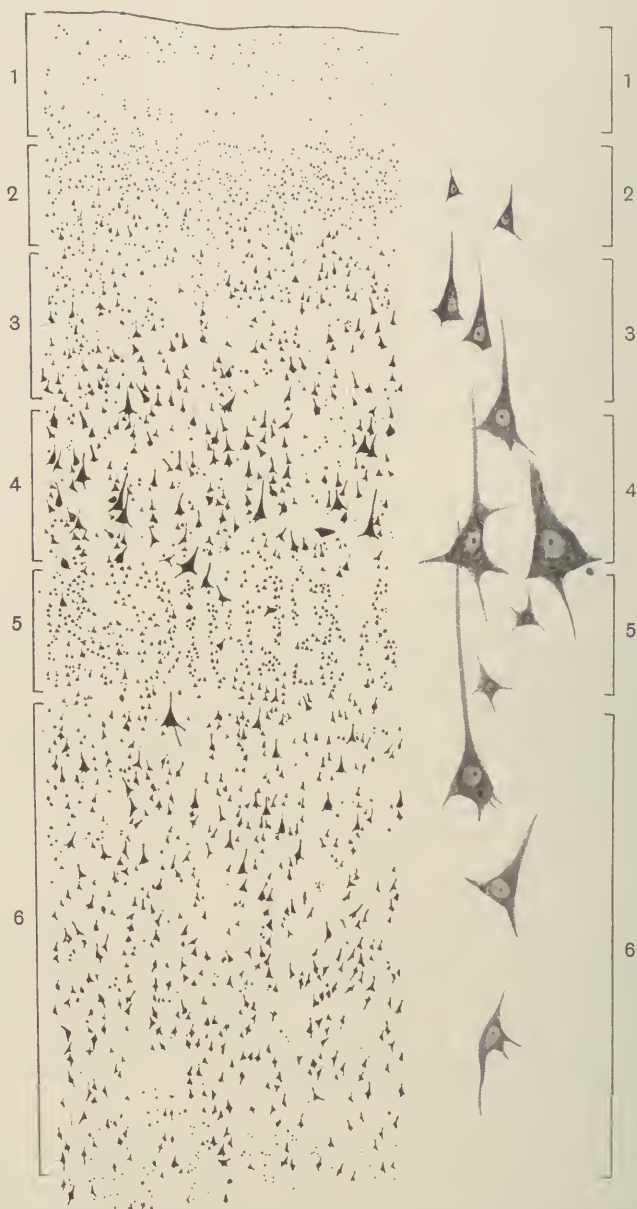


FIG. 539.—Stratigraphic analysis of the cells in the temporal gyrus of Heschl or auditory area. (*Campbell.*)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of fusiform cells.

large and their dimensions are somewhat greater than in the other regions of the temporal cortex.

The Layer of External Large Pyramidal Cells. This stratum is the distinguishing feature of the audito-sensory area. The large pyramidal cells are present in great numbers, and scattered among them are many small and medium-sized pyramidal cells. Pyramidal elements of unusual dimensions are also found in this area. Their size justifies calling them *giant cells*. Their frequency in sections is 8 to 12 for every transverse millimeter and they affect the deeper levels of this stratum. Their diameters are 45 to 50 micra in length by 25 to 40 in breadth. In form they are usually pyramidal, but may be stellate. They have a thick apical dendrite which extends toward the plexiform layer, while the basal dendrites are more branched and extend laterally in all directions. The cytoplasm contains large chromophilic bodies having a stichochrome arrangement. The nucleus of the cell is relatively small.

The Layer of Stellate Cells. This stratum is approximately 0.3 mm. in depth. The cells are arranged in columns between the radiary fasciculi. The layer is a prominent feature of this area.

The Layer of Internal Large Pyramidal Cells. This layer is not distinct enough to be made out in this region of the cortex. In the zone usually occupied by these elements only a few faintly staining and fairly large cells may be seen.

The Layer of Spindle-Shaped or Fusiform Cells. This layer is unusually deep, about 1 mm. It contains many cells whose arrangement although columnar is less distinctly of this variety than in the corresponding layer of other areas of the cortex.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE AUDITO-SENSORY AREA. *The Zonal Layer.* In this stratum there is a large number of varicose fibers of medium size and coarse type, and the layer itself is well developed.

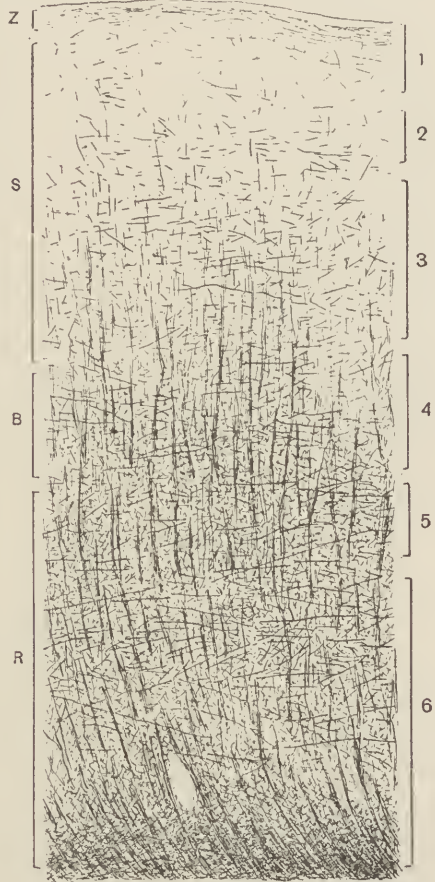


FIG. 540.—Stratigraphic analysis of the fibers in the temporal gyrus of Heschl or audito-sensory area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

The Supraradiary Layer. This stratum contains a great wealth of fibers which become arranged transversely to form a distinct line parallel with but ectal to the line of Baillarger. This is known as the *line of Kaes* which consists of fine and medium-sized fibers having a course generally parallel to the surface. A few coarse medullated fibers are seen in this zone.

The Layer of Baillarger. This layer has a great depth and is visible to the naked eye. The large number of fibers above and below it, however, make its boundaries obscure. It is by no means so prominent a feature as the corresponding layer in the visual cortex. Its constituents are chiefly fibers of medium size which run horizontally. The presence of large medullated fibers gives further prominence to this zone.

The Layer of Radiations—Radiary Layer. The radiations of Meynert in this stratum are fasciculi with many fibers of large size in addition to the smaller elements. The interradiary plexus and association fibers are the most definite characters of identification in this area. The great density of the interradiary plexus is its most prominent feature. This is due to the great number of long fibers of large size which cross the radiations at all angles and at all levels. The association fibers also form a dense plexus consisting largely of myelinated axones of medium and small size.

SUMMARY OF THE CHIEF STRATIGRAPHIC FEATURES OF THE AUDITO-SENSORY AREA. The distinguishing histological features of this area of the cortex are:

1. The presence of many giant cells either of pyramidal or stellate form above the layer of stellate cells; that is, in the layer of external large pyramidal cells.
2. The general wealth of cells in all layers.
3. The presence of a secondary transverse band parallel to the line of Baillarger and known as the *line of Kaes*.
4. The great density of the radiary layer and the presence in it of large myelinated fibers.
5. The general fiber wealth of the entire cortex.

FUNCTIONAL SIGNIFICANCE OF THE AUDITO-SENSORY AREA. The cortex covering the transverse gyri of Heschl bears a relation to auditory sensibility analogous to that of the visuo-sensory area to visual sensibility. It is a primary receiving center for auditory impulses. In this portion of the cortex auditory impressions first enter into consciousness; but as in the case of vision and body sensibility they are, so to speak, in a crude and unselected state. They produce awareness of stimulation affecting the receptors of hearing, but like the primary cortical impressions of vision and body sense they require further elaboration before they attain their ultimate associative values in auditory consciousness. As these impulses are received by the end-organs of the auditory pathway they pass inward, and after several relays finally reach the temporal cortex. Here they exist as sensations of sound comprising impressions of loudness, pitch or tone, timbre, rhythm and direction.

The loudness of a sound is conditioned by the amplitude of the vibra-

tions producing it; the pitch by the frequency; and the timbre or quality by the nature of the vibrating medium. Rhythm is also a primary sensation dependent upon the repetition of the sound and the meter of its repetition. A sound may occur but a single time; on the other hand, it may be repeated rhythmically or arrhythmically. If the repetition is rhythmical, its rate may differ from one to many times per second. The direction from which the sound reaches the body also is one of the primary factors in the sensation of hearing.

The combination of these primary auditory sensations and their associative amplification in complex synthesis results in the cognitive process which constitutes auditory knowledge.

Syndromes of the Audito-Sensory Area. Since the ear is bilaterally represented in the cerebral cortex, the destruction of one audito-sensory area will not suffice to produce a complete loss of hearing. Cases of bilateral destruction of the transverse temporal gyri of Heschl are few in number,

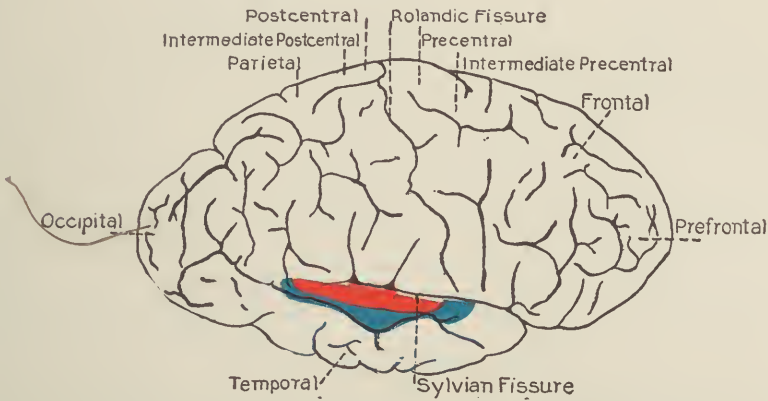


FIG. 541.—Cerebral cortex—lateral surface. Red indicates audito-sensory area. Blue indicates audito-psycho area.

but when a lesion does simultaneously destroy these gyri on the right and on the left, total deafness results. Under these circumstances the patient suffers from a complete auditory anesthesia in which all of the primary qualities of auditory sensibility fail to reach their primary receiving centers in the cortex.

Unilateral lesions involving the transverse gyri of Heschl on one side produce a dullness in the acuity of hearing, but do not produce unilateral deafness. This undoubtedly is due to the fact that the end-organs of hearing have a bilateral representation in the temporal lobes, so that when the primary receiving center upon one side is defective it impairs the general acuity of hearing upon both sides without limiting the defect to either side.

The Intermediate Temporal or Audito-Psycho Area. **BOUNDARIES AND DISTRIBUTION.** The intermediate temporal area of the cortex comprises two different types of cortex. The first is confined exclusively to the superior



FIG. 542.—Stratigraphic analysis of the cells in the intermediate temporal or auditory area. (*Campbell.*)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

temporal convolution. Its cephalic limits are indefinite and may be given as the ventral projection across the temporal lobe of the Rolandic fissure. The ventral boundary is the superior temporal fissure into the upper wall of which this type of cortex extends. The caudal boundary is the ventral prolongation of the Sylvian fissure. The cortex of this type has been described by Campbell as covering parts of the gyrus longus and gyrus secundus of the insula.

The second type of cortex in the intermediate temporal area covers the remainder of the temporal convolutions extending as far up as the horizontal and occipital rami of the intraparietal fissure and thus includes the cortex covering the angular and supramarginal gyri. The cephalic boundary of this area is not satisfactory, but the second type of cortex may be traced as far forward as the inferior postcentral sulcus. Caudally the transverse occipital sulcus is a constant boundary. The cortex covers the entire second and third temporal convolutions as well as the fusiform gyrus, and extending to the mesial surface, reaches the collateral fissure to invest the pole of the temporal lobe. It does not, however, appear on the uncus.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE INTERMEDIATE TEMPORAL AREA. The cells in the two subdivisions of the intermediate temporal area present the general characters observed in the transverse temporal gyri of Heschl.

The Plexiform Layer. This layer is present in about equal depth and distribution in cortex type I and cortex type II, although the cells are considerably less in number than in the transverse gyri of Heschl.

The layer of small pyramidal cells is somewhat deeper than in the audito-sensory area.

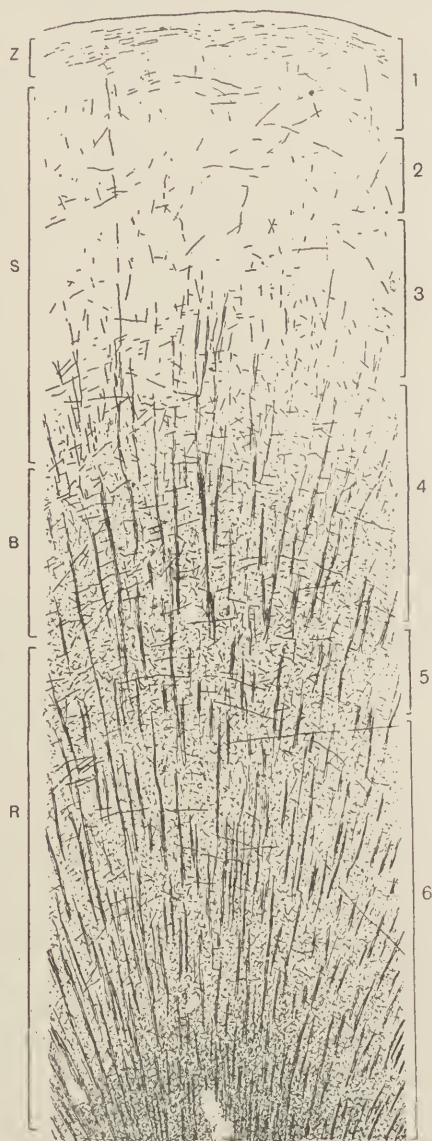


FIG. 543.—Stratigraphic analysis of the fibers in the intermediate temporal or audito-psychic area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

In the *layer of medium-sized pyramidal cells* the cells are not so numerous nor so deep.

The *layer of external large pyramidal cells* is a distinctive feature of the intermediate temporal cortex of type I. Here giant cells are present, although considerably smaller than in the transverse gyri of Heschl and much reduced in number, their frequency being 50 per cent less than in the audito-sensory area. Large pyramidal cells not of the giant type are more numerous than in the transverse gyri. In the intermediate temporal cortex of type II there are no giant cells, although the layer of external large pyramidal cells is well defined, the large cells being pyriform in shape and having an average of 40 by 20 micra in diameter.

The *layer of stellate cells* corresponds in depth and cell richness to that of the transverse gyri of Heschl.

The *layer of internal large pyramidal cells* is poorly represented both in the intermediate cortex of type I and type II, the largest elements in this stratum measuring 17 by 30 micra. They are less numerous than in the external layer. The *cells in the fusiform layer* are relatively scanty, but arranged in columns between the medullary rays.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE INTERMEDIATE TEMPORAL AREA. The *zonal layer* in both type I and type II is not well developed, being a little more marked in cortex type I than in cortex type II.

The *supraradiary layer*, although it has a greater wealth of fibers in cortex type I than in cortex type II, is less prominent than in the transverse gyri of Heschl. The line of Kaes is barely discernible.

The *layer of Baillarger* constitutes a line visible to the unaided eye and of considerable breadth, with a slight tendency to reduplication in cortex type I. It is poorly developed in cortex type II and consists mainly of short and fine fibers.

The Layer of Radiations—Radiary Layer. The radiations of Meynert are less pronounced in both types of intermediate temporal cortex than in the transverse gyri of Heschl. The interradiary plexus and association fibers attain a great wealth of fibers of small caliber more pronounced in temporal cortex type I than in cortex type II.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES IN THE INTERMEDIATE TEMPORAL AREA. The distinguishing histological features of this area of the cortex are:

1. The absence of the giant cells in the layer of external large pyramidal cells. These cells are the most conspicuous feature of the audito-sensory area.
2. The absence of large elements in the layer of internal pyramidal cells, their place being taken by smaller pyramidal elements.
3. The feeble development of the line of Kaes.

FUNCTIONAL SIGNIFICANCE OF THE INTERMEDIATE TEMPORAL AREA. The intermediate temporal cortex serves as the audito-psychic area in which the associations and correlations of primary auditory impressions take place. In this region the combinations necessary to the understanding of sounds, the appreciation of rhythm and meter, and the general interpretation of

sound vibration take place. It seems probable on the basis of clinical experience that the human brain contains a specialized temporal area for the interpretation of sound necessary to the understanding of articulate speech. The intimate necessity for an area of speech understanding is seen in the earliest periods of development when the infant first distinguishes the significance of different inflections of the voice. This recognition seems to depend primarily upon the loudness and intensity of vocal sounds. In the course of a relatively short time the significance of simple words is understood, and finally the purport of several words combined to express ideas. Some portion at least of the understanding of spoken words depends upon the activity of the intermediate temporal area in which the psychic processes are developed for word hearing. Clinical evidence indicates that the region for this word-knowledge is situated in the area adjacent to the transverse gyri of Heschl in the superior temporal convolution. This area in general corresponds to the region invested by the first type of intermediate temporal cortex. It seems to be essential to the functions of word-knowledge, or *lalognosis*. This term, by its derivation, implies not merely the recognition of articulate human speech, but also the understanding of less highly organized articulate sounds which probably serve the purposes of speech in its cruder forms, such as are observed in the lower animals and are especially well developed in the anthropoid apes.

Human speech as a cognitive process is subject to remarkable expansion, as witnessed by those pronounced differences between the speech of primitive races and that obtaining among more civilized peoples. The linguistic ability of the individual depends directly upon the degree to which the intermediate temporal area is developed, and for this reason, no doubt, it is difficult to set the definite boundaries which circumscribe it. It is of interest to know that in diseases affecting this portion of the temporal cortex, the polyglot will first lose the ability to understand and employ the foreign language last acquired, and as his speech becomes progressively affected he more and more approaches the limitations of his mother tongue which persists the longest and, in cases of recovery following complete loss, returns the first. The significance and importance of the intermediate temporal area thus becomes evident in this function of lalognosis.

Word hearing and understanding is, however, not the only auditory activity which requires extensive association and correlation of auditory sensations. Every noise and sound eventually comes to have associated value. This is especially true of musical sounds, the connotation of which is frequently developed to an extreme degree, so that vast realms of associated imagery open to the mind in response to auditory stimuli in the form of music. This function of the audito-psychic area is subject to remarkable variation in different individuals. It may be represented in a restricted and but little expanded region of the intermediate temporal cortex. If such is the case the individual attaches but little significance to the impulses of rhythm and meter, of tone and timbre. His musical syntheses are meager and his appreciation of music correspondingly scant.

Every sound and noise in nature is interpreted and endowed with special significance by the individual. In the primitive interpretation, such sounds as the rustling of the leaves, the howling of the wind, the noise of thunder, are so associated that they become attributes of a definitely visualized higher power. This imagery in the translation of sound depends upon complex syntheses which invoke the function of vision. The more precise interpretation of ordinary sounds omits this visual imagery and tends to attribute a more natural explanation to auditory perception. The rustling of the leaves is understood to mean the resultant sound from the friction of one leaf upon another producing an appreciable auditory stimulus. The howling of the wind is properly interpreted as the physical effect of obstacles to air currents. The noise of the thunder is appreciated as the result of certain electric forces attendant upon atmospheric changes and conveying their reverberation as air waves to the ear. These syntheses in hearing knowledge, *auditognosis*, indicate more complex syntheses dependent upon more numerous associations. Recognition of the natural causes in the production of the noise of thunder implies a vaster amount of associative processes than the attribution of this natural phenomenon as a quality of a higher being. This association of sounds and noises with material objects constitutes a poly-esthesis synthesis in which no one sense alone is capable of creating an adequate conception, but in which several senses, as for example hearing and sight, and possibly touch and smell, participate. The association of sounds with objects undoubtedly requires the perception of both visual and auditory activities in proper correlation. The clinical and experimental evidence upon which to base the assumption that the circumambient portion of the cortex surrounding the superior temporal convolution serves for this synthesis of vision and hearing in the identification of sounds with objects, is not extensive enough completely to substantiate the hypothesis. There are, on the other hand, reported cases in which this fact seems to be definitely indicated, and tentatively, at least, the theory may be accepted with reference to the portion of the intermediate temporal area corresponding to the second type.

In summary, the intermediate temporal area as represented by its first type is essentially an area of auditory speech knowledge, *lalognosis*. This region may conceivably extend into the second type of intermediate temporal cortex in which are also represented the understanding of music and probably the cognitive processes necessary for the identification of objects with sounds and noises.

Syndromes of the Intermediate Temporal Area. Lesions in the intermediate temporal cortex limited to its first type lead to a condition known as word-deafness or speech-deafness. In this condition, the patient hears the sound of spoken words, but does not understand their meaning. If asked to raise his right hand, he will reply: "I hear you speaking but do not know what you say." Hearing of sounds other than those of articulate speech may be preserved and the proper associations attached. The clinking of coins, the ringing of a bell, the jingling of keys close to the patient's ear,

may all be identified and the source of the stimulus properly differentiated. The patient will say: "I hear the clinking of money," or "I hear a bell," or "I hear the jingling of a bunch of keys."

In word-deafness not only is the ability to identify the meaning of spoken words impaired, but the patient's internal hearing of his own speech is also defective. He may use the wrong words—the plural where he means the singular, the feminine pronoun where he should use the masculine. This misuse of words is known as *heterophasia*. In some cases his internal hearing of his own speech is so defective that he does not make grammatical construction although formerly he was able to do so in his own articulate speech. This condition is known as *agrammatism*. The failure in articulate speech due to the lack of proper internal auditory supervision on the part of the patient may result in speech production of a jumbled and diffuse expression including the use of words that do not exist and words not in their proper relation to each other. This constitutes a *jargon aphasia* or *paraphasia*.

More extensive lesions of the temporal cortex may produce a *tone* or *musical deafness* in those who have a special talent for music. This condition is known as *amusia*. It seldom exists in a pure state, but is not infrequently combined with complete word-deafness, and in all cases some degree of impairment in word-hearing is present.

In certain individuals the temporal area of the cortex appears to be congenitally defective so that the combinations of musical tones which ordinarily produce harmonies give rise to a sensation of discomfort and disharmony. This condition in certain respects is parallel to dyschromatopsia or color blindness. Congenital tone distortion is known as *dysmusia*.

The exact part of the cortex in which disease produces these symptoms has not been definitely determined, but such clinical evidence as is available points to the intermediate temporal cortex of the second type.

Still more extensive lesions of the intermediate temporal cortex lead to a condition known as *mind-deafness* or *psychic deafness*. The term mind-deafness is applied to the pathological condition in which the patient is unable to interpret or recognize ordinary sounds, that is, defects in the cognitive process necessary to identify sounds and noises with the objects producing them. The patient may recognize the barking of a dog or the ringing of a bell or the jingling of a bunch of keys as some sound or noise; but he is not able to correlate this sound with the object producing it. Sounds and noises convey no meaning to the mind in cases of psychic deafness. This defect in hearing is invariably accompanied by word-deafness, and if the patient is proficient in music, by an *amusia* also. The decrease in the auditory aditus and the proper interpretation of auditory sensations naturally leads to considerable blunting of the intellect, so that the patient appears to have a distinct loss of mental alertness.

In summary, the principal clinical features which may be ascribed to lesions of the intermediate temporal cortex are:

1. Disturbances in the audito-psychic activities including word-deafness with the retention of sound and object association and the appreciation of musical tones.

2. The loss of proper internal supervision of articulate speech resulting in heterophasia, agrammatism, jargon aphasia or paraphasia.

3. Amusia, the loss of the proper appreciation of musical tones. This is usually combined with a more or less complete word-deafness with an attendant paraphasia, with the retention of proper object-sound association.

4. Mind-deafness which includes loss of word-hearing, loss of the appreciation of musical tones and obliteration of object-sound association.

The left temporal lobe in right-handed individuals appears to be dominant in the auditory function. In cases presenting psychic disturbances in hearing the lesion is usually located in the left temporal lobe.

CHAPTER XLVIII

THE ENDBRAIN

THE LIMBIC AND INSULAR AREAS

Constituents of the Limbic Area (Archipallial Rhinencephalon). The limbic area consists of the gyrus cinguli, the gyrus hippocampi, including the subiculum and cornu Ammonis, the gyrus dentatus and gyrus uncinatus. It also includes such rudimentary and atrophic structures as the gyrus fasciolaris, gyri Andreae Retzii, the indusium griseum and striæ medullares.

THE GYRUS CINGULI. Boundaries and Distribution. The gyrus cinguli is bounded above by the supracallosal fissure and ventrally by the callosal fissure. It surrounds the corpus callosum from the splenium to the rostrum.

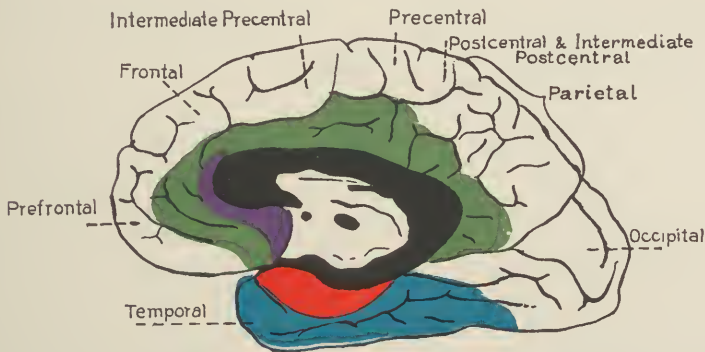


FIG. 544.—Cerebral cortex—mesial surface. Red indicates olfactory area. Blue indicates temporal area. Green indicates limbic area. Purple indicates gyrus subcallosus. Black indicates fascia dentata, gyrus fasciolaris and corpus callosum.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE GYRUS CINGULI.
The Plexiform Layer. This stratum presents no distinguishing feature.

The Layer of Small Pyramidal Cells. This layer is of inconsiderable depth, and the cells are not numerous, especially in the portions immediately adjacent to the corpus callosum.

The Layer of Medium-Sized Pyramidal Cells and the Layer of External Large Pyramidal Cells. The layer of medium-sized pyramidal cells is ill-defined. Together with the next succeeding layer of external large pyramidal cells, it occupies a single deep stratum composed of cells of approximately equal size. These cells measure 15 by 30 micra to 20 by 37 micra. They have a well defined apical and two or three basal dendrites. The chromophilic particles stand out with great prominence. These cells are the most distinctive characteristic of the gyrus cinguli.

The Layer of Stellate Cells. The character of this layer is the most im-

portant identifying feature of this area, since no definite stellate cells may be distinguished.

The Layer of Internal Large Pyramidal Cells. This stratum is feebly represented.

The Layer of Fusiform or Spindle-Shaped Cells. This layer is similar to that in other regions of the cortex.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE GYRUS CINGULI. *The Zonal Layer.* This fiber stratum is indistinct.

The Supraradiary Layer. This stratum has a fairly rich fiber representation with axones running in all directions.

The Layer of Baillarger. Although this layer may be distinguished, it has no striking characteristics.

The Layer of Radiations—Radiary Layer. The radiations of Meynert lack solidity on account of the absence of larger fibers. The interradiary plexus together with the association fibers are meagerly developed.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES OF THE GYRUS CINGULI. The distinguishing histological features of this area are:

1. The absence of any distinct medium-sized and external large pyramidal cells.

2. The appearance of a peculiar type of cell—the *chromophilous cells*—in the layer of



FIG. 545.—Stratigraphic analysis of the cells in the gyrus fornicatus. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

medium-sized pyramidal cells and the layer of external large pyramidal cells.

3. The absence of a stellate layer.

4. The meagerness of the layer of internal large pyramidal cells.

THE GYRUS HIPPOCAMPI. Upon transverse section the hippocampal formation presents three portions: 1, the *subiculum*; 2, the hippocampal portion of the *cornu Ammonis*; and 3, the dentate portion of the *cornu Ammonis*.

The subiculum is situated upon the surface of the hippocampal formation while the cornu Ammonis is in relation with the depths of the hippocampal fissure. The cornu Ammonis and the subiculum together have the form of the letter S. The more ventral curved portion of the S is represented by the subiculum, while the more dorsal curve represents the cornu Ammonis. In the concavity of the curve formed by the cornu Ammonis is lodged the gyrus dentatus. This latter gyrus represents a much altered area of the cortex, modified by reason of its inversion and because of its juxtaposition with the plexiform layer of the cornu Ammonis. The gyrus dentatus in transverse section appears kidney-shaped in outline. In its hilus it lodges the dentate portion of the cornu Ammonis.

Description of the Cells in the Subiculum. There are two features which characterize the cellular stratification in the subiculum: (1) The presence of independent islands of minute cells in the plexiform layer, and (2) the arrangement of the layer of internal large pyramidal cells.

The isolated islands consist of about one hundred small, deeply staining, triangular cells with diameters of about 5 micra.

In the layer of internal large pyramidal cells, the cellular elements are large, pyramidal and elongated. They have a long apical dendritic process and are arranged in regular, parallel rows, for which reason this layer is referred to as the *stratum radiatum*. This cellular arrangement is found in the cornu Ammonis as well as the subiculum. There is a slight difference, however, since the cells in the subicular region are much longer and the chromophilic substance stains more intensely.



FIG. 546.—Stratigraphic analysis of the fibers in the gyrus fornicatus. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

Description of the Fibers in the Subiculum. The arrangement of the fiber system in the subiculum is not distinctive.

The medullary substance is thick and contains two layers of myelinated fibers: a deep layer which is composed of fine fibers apparently belonging to the commissural system; and a superficial layer which is of larger caliber. The fibers of this layer are continuous with the fibers of the alveus and represent axones of the pyramidal cells of the cornu Ammonis and subiculum. They are associated with the posterior fasciculus of the cingulum and connect it with the cornu Ammonis and with the hippocampus.



FIG. 547.—Schematic representation of the cornu Ammonis and of the gyrus dentatus, seen on vertical transverse section. The areas, dentate and hippocampal, of the cornu Ammonis are indicated. (*Déjerine.*)

PM—Polymorphous layer. LPL—Large pyramidal layer. SPL—Small pyramidal layer. GL—Granular layer. ML—Molecular layer. L—Stratum lacunosum. *l*—Cells of stratum lacunosum. FDF—Fimbriodentate fissure. MF—Mossy fibers of Cajal. *tf*—Tangential fibers. SO—Stratum oriens of polymorphous cells. *O*—Cell of stratum oriens, Golgi type II, arched and horizontal axones. *P*—Layer of pyramidal cells. *p*—Cells of pyramidal layer. *R*—Stratum radiatum.

STRATIGRAPHICAL DESCRIPTION OF THE CELLS IN THE CORNU AMMONIS.

The Plexiform Layer. This stratum corresponds to the plexiform layer in other areas but it comprises several constituent zones:

- (a) The *stratum plexiforme*, made up of tangential fibers.
- (b) The *lamina medullaris involuta*, in which two types of cells may be distinguished—the fusiform type of Cajal, and cells of Golgi type II.
- (c) The *stratum lacunosum*, which contains cells of the same type as those found in the above layer, in addition to a great number of myelinated fibers.
- (d) The *stratum radiatum*, which consists of a zone limited above by the stratum lacunosum and below by the layer of pyramidal cells. It is almost exclusively composed of the dendritic end arborizations. It contains



FIG. 548.—Stratigraphic analysis of the cells in the hippocampal area. (*Campbell*.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of large and irregularly disposed pyramidal elements.

several types of cells including scattered pyramidal cells of medium size, triangular and fusiform cells, all of which have apparently migrated from the stratum lacunosum.

The Layer of Pyramidal Cells. This stratum corresponds to the layers of small, medium and large pyramidal cells of the usual cortical type. The pyramidal cells of the cornu Ammonis present a special form in the region of the subiculum. Here they possess a fusiform or oval body, and have two varieties of dendrites, those which are descending and those which are ascending. The axones of these cells are either connected with the soma or with one of the large dendrites. They may be traced into the alveus.



FIG. 549.—Stratigraphic analysis of the fibers in the hippocampal area. (Campbell.)

Note the lamina medullaris externa, the slender radiations of Meynert, the open character of the interradiary plexus, and the bundles of cross-cut association fibers.

The Stratum Oriens. This stratum corresponds to the layer of fusiform cells and contains some small pyramidal elements. Some of these cells have arched axones, while the axones of others take a horizontal course.

The *basal* or *medullary element* in the cornu Ammonis is the *alveus*, which lies immediately adjacent to the temporal horn of the lateral ventricle and is covered by a layer of ependymal cells.

STRATIGRAPHICAL DESCRIPTION OF THE FIBERS IN THE CORNU AMMONIS. *The Zonal Layer.* This stratum consists of a superficial medullary lamina and a middle medullary lamina which forms the stratum lacunosum. The superficial medullary lamina is rich in myelinated nerve fibers, most of which have a tangential arrangement. The stratum lacunosum contains numerous axones disposed in parallel fasciculi which extend from the region of the gyrus dentatus to the subiculum.

The Supraradiary Layer. This stratum is broad and dense, containing the ramifications of axones. The majority of the fibers represent the end arborization of the two types of cells found in the stratum oriens; that is, the cells having arched axones and the cells with horizontal axones.

The Layer of Baillarger. This stratum is a broad one but does not contain many fibers of large caliber. The elements have an irregular course and do not tend to run parallel as in other regions.

The Layer of Radiations—Radiary Layer. The radiations of Meynert cease at the boundary line between the subiculum and the cornu Ammonis.

They become gradually less prominent in the subiculum as they approach this boundary. This is accounted for by the fact that the cortex of the cornu Ammonis is no longer in continuity with the medullary substance but has subjacent to it the cavity of the temporal horn of the lateral ventricle. In place of the radiations of Meynert, the radiary plexus and association fibers, are the many parallel, slender fasciculi which form the alveus.

THE GYRUS DENTATUS. The gyrus dentatus is a small cerebral convolution whose plexiform layer faces the plexiform layer of the cornu Ammonis. This has been determined by the inversion of that portion of the hippocampal region which borders upon the hippocampal fissure. The gyrus dentatus is bounded above by the fimbria and the dentate portion of the cornu Ammonis. Laterally and ventrally it is bounded by the hippocampal portion of the cornu Ammonis from which it is separated by the hippocampal fissure. Mesially the gyrus dentatus is free and projects inward between the fimbria and the subiculum.

The medullary substance of the gyrus dentatus is represented by the alveus which, however, is in direct contact with the convolution itself. The white substance of the dentate gyrus is separated from the cortical area by a second layer of cortex which contains a plexiform, a pyramidal and a polymorphous stratum. This interposed cortical area is part of the cornu Ammonis. As a result of the superposition of these two areas of cortex, the fibers from the gyrus dentatus are compelled to traverse a portion of the cornu Ammonis before reaching their destination in the alveus. The dentate gyrus, therefore, may be regarded as an inverted area of the cortex embraced on its ventral and lateral aspects by the cornu Ammonis, and itself embracing the dentate region of the cornu Ammonis.

The ectal surface of the dentate cortex is in relation with the hippocampal fissure, while its ental surface is directed toward the *hilus gyri dentati*. Seven strata are recognized in passing from the superficial to the deep part of the dentate gyrus:

The plexiform layer, which borders upon the hippocampal fissure and is contiguous with the plexiform layer of the cornu Ammonis; the granular layer, which consists of modified pyramidal cells of small and medium size; the layer of polymorphous cells, in which a transition occurs from the dentate gyrus to the dentate portion of the cornu Ammonis. This region contains a plexiform layer, a layer of giant pyramidal cells, a layer of polymorphous cells and the alveus.

In this cortical area there is a fusion of two zones of the cortex. Beginning at the hippocampal fissure and proceeding toward the ventricle, the first three layers belong to the dentate gyrus; immediately following are four layers constituting the dentate portion of the cornu Ammonis.

The *plexiform layer* of the gyrus dentatus is similar to that in other regions of the brain. It contains a large number of tangential fibers and two varieties of cells, triangular or migratory granule cells, and the cells of Golgi type II.

The *granular layer* or *stratum granulosum* is composed of several layers

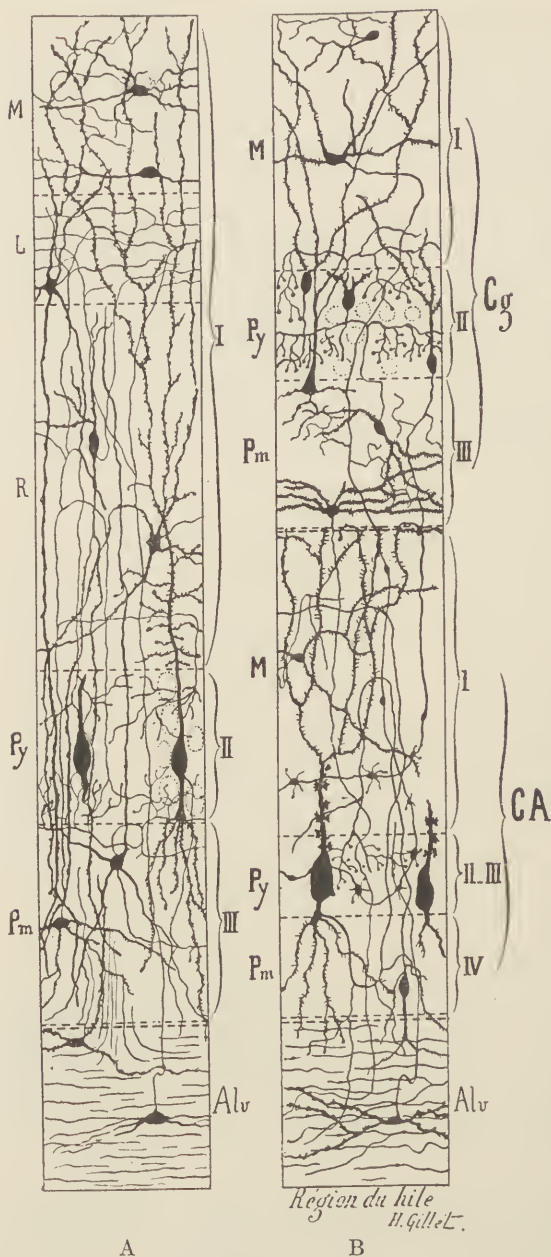


FIG. 550.—A. Schematic representation of the cortex in the hippocampal region. (*Déjerine*.)

I. Molecular layer including the molecular stratum *M*, the lacunar stratum *L* and the radiate stratum *R*. II. Layer of pyramidal cells *Py*. III. Layer of polymorphous cells. *Pm*, the stratum oriens. *Alv*, alveus.

B. Schematic representation of the cortex in the region of the hilus of the gyrus dentatus showing the superposition of the two types of cortex.

In *Cg*, I, II, and III represent the molecular layer, the layer of giant cells and the polymorphous layer respectively in the hilus of the dentate gyrus. In *Ca*, I, II and III represent the same layers as in *Cg* in the dentate portion of the cornu ammonis. *Alv*—alveus.

of round or ovoid cells. These are the granules of the dentate gyrus which are also known as the *myelocytes of Robin*. They are probably analogous to the pyramidal cells of other areas of the cortex.

The layer of polymorphous cells is analogous to the layer of fusiform or spindle-shaped cells in other parts of the cortex. It is limited above by the stratum granulosum and below by the plexiform layer of the dentate portion of the cornu Ammonis. Three types of cells have been distinguished in this stratum; i.e., a superficial layer of pyramidal cells, a middle layer of small cells, and a deep layer of fusiform cells.

The fibers of the gyrus dentatus and the dentate portion of the cornu Ammonis are collected in the dorsal aspect of this area where they enter the alveus or the fimbria.

THE STRIÆ LONGITUDINALES MEDIALES AND LATERALES AND THE INDUSIUM GRISEUM. The middle and lateral striæ consist of longitudinally directed bundles of medullated nerves of medium size. They are contained in a thin velar layer of gray matter, the indusium griseum, which rests upon the

dorsal surface of the corpus callosum. In this thin layer of gray matter are many scattered medium-sized pyramidal cells with short processes. They are irregular in their arrangement and contain but little chromophilic substance. Traced caudally, this layer of the indusium griseum may be followed as far as the dentate gyrus. Followed cephalad, the striæ undergo reduction and ultimately reach the cortex below and in front of the origin of the corpus callosum. The entire structure of the indusium and the two striæ represents the atrophic remnants of the gyrus supracallosus.

THE GYRUS FASCIOLARIS, GYRUS UNCINATUS AND GYRI ANDREÆ RETZII. The gyrus fasciolaris, gyrus uncinatus and gyri Andreæ Retzii represent a type of cortex which in its cellular and fiber characters is closely related to the hippocampal formation.

All of the structures included in this group of cortical areas constitute the archipallial portion of the rhinencephalon.

THE PRIMORDIAL RHINENCEPHALON. The primordial rhinencephalon is usually referred to as the peripheral portion of the rhinencephalon. It comprises the olfactory bulb and tract, the trigonum olfactorium, the area parolfactoria, the anterior perforated space, the gyrus subcallosus and the diagonal band of Broca.

The gray matter of the *olfactory bulb* presents some tendency toward stratification. In macrosomatic animals it contains a cavity which is continuous through the olfactory tract with the lateral ventricle. The bulb consists of five layers: The layer of superficial nerve fibers, the layer of olfactory glomeruli, the plexiform layer, the layer of mitral cells and the layer of granule cells and deep nerve fibers.

The layer of superficial nerve fibers is made up exclusively of olfactory fibers arising in the olfactory membrane, and entering the olfactory bulb as the *fila olfactoria*.

The olfactory glomeruli are small spherical or ellipsoid masses from .2 to .25 mm. in diameter. In them, the olfactory fibers terminate in order to form synapses with the dendrites of the mitral cells.

The plexiform layer is finely granular and contains small fusiform cells.

The layer of mitral cells consists of large or giant triangular elements, in general having a mitral form. The axones of these cells constitute the olfactory tract, while their dendrites, conjoined with the end arborization of the olfactory fibers, form the olfactory glomeruli.

The granular layer, which is the deepest stratum in the olfactory bulb, consists of granule cells and cells of Golgi type II, together with a number of myelinated fibers.

The *olfactory tract* consists of fibers for the most part arising in the mitral cells of the bulb, together with a number of scattered pyramidal cells of large size. Impressions coming in from the olfactory mucous membrane reach the olfactory bulb and are either transmitted by the mitral cells directly to the gyrus uncinatus by way of the lateral olfactory root, or receive a relay in the pyramidal cells of the olfactory tract or in the trigonum olfactorium.

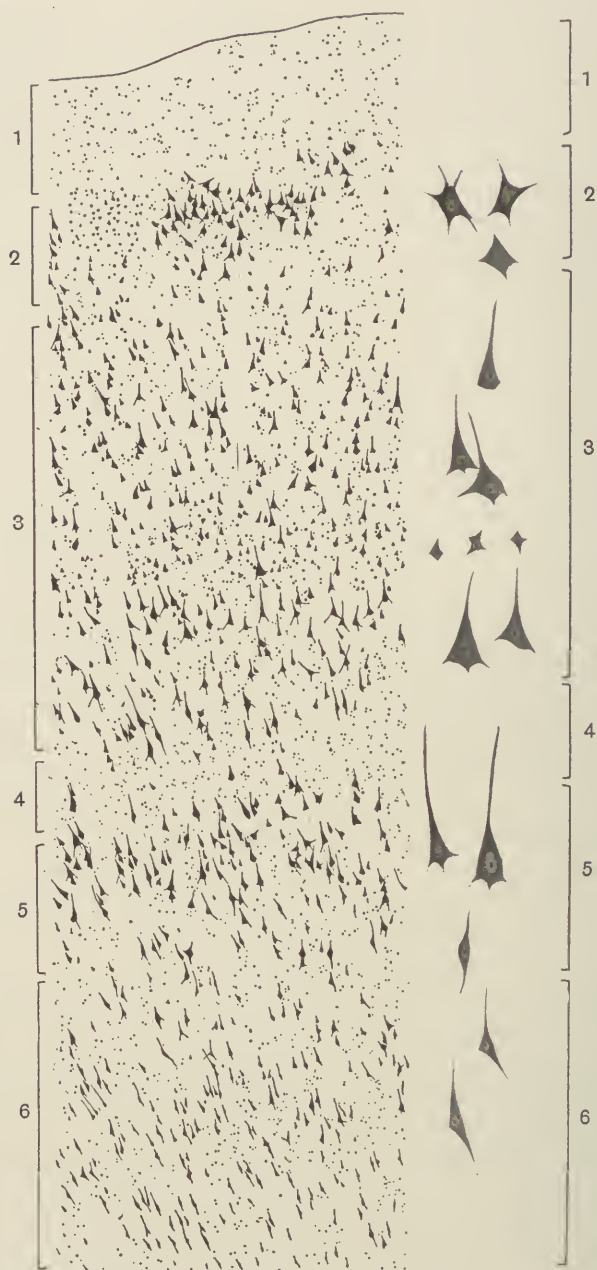


FIG. 551.—Stratigraphic analysis of the cells in the lobus pyriformis. (*Campbell.*)

1. Plexiform layer. 2. Layer containing clusters of large stellate cells. 3. Layer of pyramidal cells. 4. Layer containing no cells. 5. Layer of elongated pyriform cells. 6. Layer of fusiform cells.

The *olfactory trigone* consists of three layers: a plexiform layer, a layer of medium-sized pyramidal cells, and a layer of polymorphous cells, which in their general stratification correspond somewhat to other cortical areas.

The *gyrus subcallosus* and *area parolfactoria* are situated beneath the rostrum of the corpus callosum on the mesial surface of the hemisphere. They contain a recognizable plexiform layer and a rather indefinite stratum of medium-sized pyramidal cells; while situated more deeply there are occasional deeply staining elongated pyramidal cells.

FUNCTIONAL SIGNIFICANCE OF THE LIMBIC LOBE AND RHINENCEPHALON. The marked development of the rhinencephalon in macrosomatic animals and its evident retrogression in such animals as depend but little upon the sense of smell, constitute one of the strongest arguments in favor of allocating the sense of smell to the limbic area. The sense of taste for aromatic and volatile substances depends upon the olfactory sense, and it is probable that the gustatory sense proper is also dependent upon the rhinencephalon. The more exact differentiation of the various areas in the limbic lobe in their special relation to the elaboration of olfactory sensations is but little understood. The sense of smell in man is so poorly developed and its clinical importance of such little moment, that the attempt to make further differentiation in this complex zone serves but little purpose.

In one particular the limbic lobe is important; namely, in a condition known as *uncinate fits*, a disorder arising from tumor or disease of the *gyrus uncinatus*. The symptoms of this disturbance are peculiar olfactory sensations for which there is no provocation and which are, therefore, olfactory hallucinations. As a rule, these purely subjective olfactory impressions are of a disagreeable character.



FIG. 552.—Stratigraphic analysis of the fibers in the lobus pyriformis. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

The patient will complain of an odor for which there is no cause in his environment. Associated with these subjective sensations of smell are the spasmodic occurrences of peculiar fits or paroxysmal attacks in which the patient complains of a sense of unreality and remoteness and is then seized with a peculiar shuddering or even an actual convulsive attack. During the unconscious period the arm on the side opposite the lesion may be moved in a slow, deliberate but purposeless manner. The attacks may be succeeded by a transient loss of the sense of taste and smell.

Often in cases of tumor of the gyrus uncinatus these uncinatiform fits are accompanied by an anesthesia of the same side of the face about and above the eye, a protrusion of the eyeball upon the same side (exophthalmos) and a paralysis of the third nerve. These symptoms are constant and are caused by the pressure of the tumor upon the cavernous sinus in such a manner as to compromise the venous return from the orbit, produce exophthalmos and compress the ophthalmic division of the fifth nerve as well as the oculomotor nerve.

The Insular Area. This region of the cortex lies in the depths of the Sylvian fissure and is surrounded by the *sulcus circularis*. It consists of five gyri separated into two groups by the *sulcus centralis insulæ*. Three of these gyri lie in front and two behind the sulcus. The gyri are separated from each other by lesser sulci and are indicated from before backward as the *gyrus brevis primus*, *gyrus brevis secundus*, *gyrus brevis tertius*, *gyrus longus* and *gyrus posterior secundus*.

The insular area is concealed from view by the frontal, parietal and temporal opercula. Two types of cortex are found in connection with its gyri. The first type (type I) corresponds to the area of the *gyrus brevis primus*, *gyrus brevis secundus* and *gyrus brevis tertius*, with the exception of a small dorsal portion in each of these convolutions where the cortex represents a combination of frontal and anterior insular type. Type I is known as the *anterior insular type*. The second type (type II) covers the *gyrus posterior secundus* and *gyrus longus*, with the exception of its upper and lower extremities where, again, the type of cortex is a combination of several other types. The *sulcus centralis insulæ* is an approximate dividing line between the two types of cortex of the insula.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE INSULA. In both insular types of cortex the *plexiform layer* presents no identifying features.

The *layer of small pyramidal cells* of both types of cortex do not contain so many cells as the corresponding layer in other parts of the cortex.

The *layer of medium-sized pyramidal cells* in both insular types of cortex is not up to the average depth and its demarcation from the subjacent layer is not so well defined.

In the *layer of external pyramidal cells* of the anterior insular cortex these cellular elements are very numerous and stain deeply. These cells differ in point of size and configuration from those in other regions. They are smaller, more tapering and much elongated, with an apical dendrite which is long drawn out. The base of the cell is angular. From its angles three to five

delicate processes are given off. In approaching the *limen insulæ* these cells become reduced in size and number.

The posterior insular area presents a type of cortex different in some respects from the anterior area. The layer of external pyramidal cells shows a decrease in number. These cells show a reversion to the usual type. They are not elongated but bear a general resemblance to the cells in the audito-psychic cortex.

The *layer of stellate cells* in the anterior insular area is recognized with difficulty as a distinct stratum. It contains some triangular and polymorphous elements which mark its presence. The layer of stellate cells in the posterior insular area is much more prominent.

The *layer of internal large pyramidal cells* in the anterior insular area is not so deep as the external layer, but is made up of cells corresponding in detail to the general character of the cells in the outer layer. As the *limen insulæ* is approached there are certain prominent cells which are bipolar, spindle-form and very large. They stain intensely, and have much in common with the cells of the limbic lobe. They form a particularly striking feature throughout the short insular gyri.



FIG. 553.—Stratigraphic analysis of the cells in the insular area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

In the posterior insular area this layer shows a tendency to assume the arrangement and character of the cells in the temporal cortex.

The layer of fusiform cells in both types of cortex is a deep stratum containing many medium-sized triangular and spindle-shaped cells.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE INSULA. *The Zonal Layer.* This stratum in all parts of the insula is particularly deep. It does not contain many large fibers and fibers of Martinotti are rare.

The Supraradiary Layer. This stratum is not well defined in the anterior area. In the posterior area it becomes more prominent due to the increased number of transverse fibers, and at the junction of the upper with the middle third of the layer, a faint line of Kaes appears.

The Layer of Baillarger. This stratum in the anterior insular area is barely recognizable. It consists of a few fibers of fine caliber. In the posterior region the line of Baillarger is distinct and contains many large and medium-sized fibers; it resembles in general the conditions of the parieto-temporal cortex.

The Layer of Radiations—Radiary Layer. The radiations of Meynert are composed of small fibers which constitute slender fasciculi. In the anterior region, coarse medullated fibers do not appear. In the posterior area, on the other hand, large fibers are more common and give a greater prominence to the fasciculi. The interradiary plexus and association system shows a general weakness of fibers which is more pronounced in the anterior than in the posterior area. In



FIG. 554.—Stratigraphic analysis of the fibers in the insular area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

the posterior area there is a considerable number of long medium-sized association fibers which pass transversely across the interradiary spaces.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES OF THE INSULA.

The insular area, according to its histological characters, consists of two distinct types of cortex, an anterior and a posterior region. The anterior insular region allies itself with the olfactory cortex and is characterized by:

1. A layer of external large pyramidal cells which become much elongated.
2. Bipolar cells of stellate shape in the layer of internal large pyramidal cells.
3. A reduction of the layer of stellate cells.

The second type of cortex, the posterior insular region, allies itself with the temporal cortex. Its cells, in the layer of external large pyramidal cells, are similar to those of the temporal area, and the stellate layer assumes much prominence.

FUNCTIONAL SIGNIFICANCE OF THE INSULA. It is probable that the insula represents one of the older portions of the cortex. It is more prominent in lower mammals than in man and the higher apes. The allocation to it of a center for the control of speech is not supported by histological evidence.

The posterior insular area presents a type of cortex closely resembling the temporal cortex and in all probability is functionally associated with this region of the brain. The anterior insular region is histologically related to the olfactory cortex, and it is probably related to the senses of smell and taste.

CHAPTER XLIX

THE ENDBRAIN

THE PARIETAL, FRONTAL AND PREFRONTAL AREAS

The Parietal Area. The landmarks of the parietal area are the intraparietal, the parieto-occipital and the calloso-marginal fissures.

BOUNDARIES AND DISTRIBUTION. On the lateral surface of the hemisphere, the boundaries of this area are not definite. The cephalic limit of the parietal area is determined by the vertical limb of the intraparietal fissure. Its caudal boundary is the lateral portion of the parieto-occipital fissure. while its dorsal boundary is the horizontal limb of the intraparietal fissure.

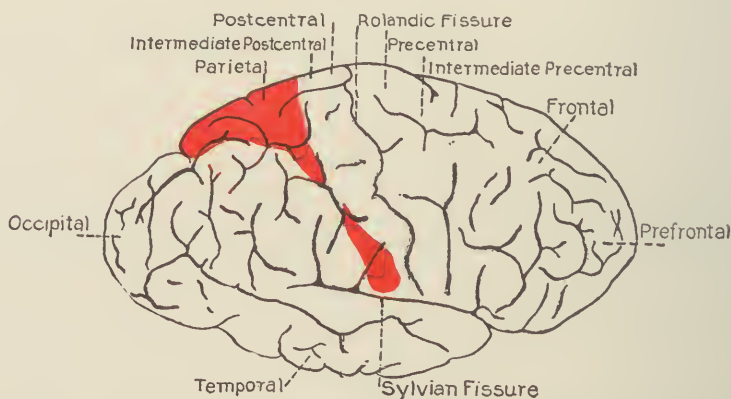


FIG. 555.—Cerebral cortex—lateral surface. Red indicates parietal area.

This type of cortex on the lateral surface covers the superior parietal convolution and a small area in the cephalic portion of the angular gyrus. On the mesial surface the cephalic boundary is the upturned end of the calloso-marginal fissure which forms the caudal boundary of the paracentral lobule. On the mesial surface the parietal cortex covers the precuneus.

STRATIGRAPHICAL DESCRIPTION OF THE CELLS IN THE PARIETAL AREA.
The Plexiform Layer. This stratum does not show any marked difference from the adjacent areas.

The Layer of Small Pyramidal Cells. This stratum presents no distinctive characteristics.

The Layer of Medium-Sized Pyramidal Cells. This stratum in its general features resembles the intermediate postcentral area.

The Layer of External Large Pyramidal Cells. The general resemblance of this layer to that in the intermediate postcentral area is marked. There is, however, an appreciable reduction in the size of the cells in the parietal

area, especially the pyramidal cells which have a large amount of chromophilic substance. They resemble in their arrangement and characters the corresponding cells in the temporal area, while the large pyramidal cells in the visuo-psychic area are in such marked contrast to those in the parietal region that the boundary of the occipital area may be easily made on the basis of this distinction. The pronounced decrease in size of these cells in the limbic area also serves as a sufficient differentiation between the limbic and the parietal areas.

The Layer of Stellate Cells. This stratum is prominent and well developed. It does not serve the purposes of topographical differentiation, as it corresponds closely to the stellate layer in the adjacent regions.

The Layer of Internal Large Pyramidal Cells. This stratum may be easily distinguished, but its constituent cells are neither so large nor so numerous as in the external layer. It is not definite enough to serve as a differentiating character from the temporal, limbic, postcentral or visual areas.

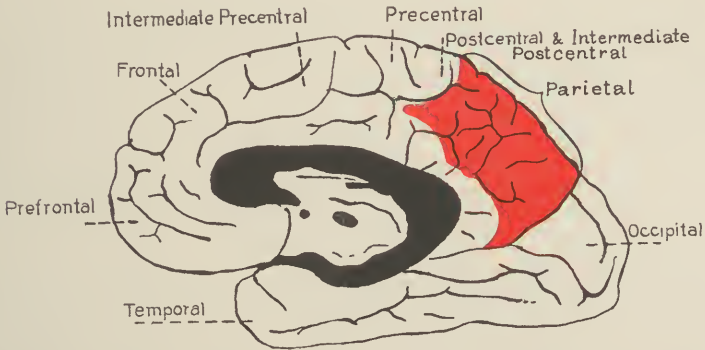


FIG. 556.—Cerebral cortex—mesial surface. Red indicates parietal area.

The Layer of Fusiform Cells. This stratum is deep and the cells are larger and susceptible of division into an ectal and an ental layer. The cells in the more superficial zone are larger than those in the deeper stratum. In total depth the parietal cortex corresponds to the temporal and postcentral areas.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE PARIETAL AREA.
The Zonal Layer. This fiber stratum is poorly developed. It contains many fine varicose fibers with a few larger elements. Heavily myelinated fibers are not present. The inner boundary of this layer is ill-defined.

The Supraradiary Layer. This layer contains fibers of medium size, and increases in its density as the line of Baillarger is approached. The fibers are all of medium caliber and form an irregular network. An occasional vertical fiber of Martinotti is observed.

The Layer of Baillarger. In this stratum the line of Baillarger is duplicated. The deeper of these, the *line of Kaes*, is situated midway between the external line and the white substance, and corresponds in position to the layer of internal large pyramidal cells. The second line in this layer has

a greater depth than the first. This fact serves as one of the distinguishing features of the parietal area.



FIG. 557.—Stratigraphic analysis of the cells in the parietal area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

Layer of Radiations—The Radiary Layer. The radiations of Meynert are composed of fine and medium-sized fibers in which a coarse myelinated fiber occasionally appears. The fibers of the interradiary plexus are intermingled with those probably belonging to the inner line of Baillarger, which makes the definition between the post-central and temporal areas somewhat difficult. The definition between the limbic and the occipital regions is relatively more easily discernible.

The fiber representation in the parietal area is less than that of the intermediate post-central, and more than that of the intermediate temporal area.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES OF THE PARIETAL AREA. The distinguishing histological features of this area of the cortex are:

1. The absence of any large and well defined cells in the layer of external large pyramidal cells.

2. The absence of any large pyramidal elements in the layer of internal pyramidal cells.

3. The presence of re-duplication of the line of Baillarger in which the second line (line of Kaes) is deeper than the first.

FUNCTIONAL SIGNIFICANCE OF THE PARIETAL AREA. Experimental and clinical evidence is not sufficiently convincing concerning the functions of the

parietal area. Its close histological association with the postcentral and intermediate postcentral type of cortex would seem to warrant the supposition that it is intimately connected with somestheto-sensory activities. From the fact that it occupies an interpolated position between the visual and somestheto-sensory fields, it has been regarded by some authorities as the common blending zone wherein visual and somestheto-sensory associations take place. In this light it is conceivable that the parietal area serves for the construction of those concrete ideas of external objects which depend upon syntheses of vision and body sense. The quality of an object which is seen may be further amplified by the experience gained through actual contact with this object. The combinations, therefore, of sensory perceptions arising from somesthetic sensibility and vision would determine more concrete ideas of material objects than would be the case were either of these types of sensibility acting alone within its own restricted field.

The relation which the parietal cortex bears, not only to the visual and somestheto-sensory, but to the intermediate temporal area as well, is suggestive of the relatively large number of syntheses which take place in connection with concrete ideas. The recognition of the shape and size of a black cubical object through the sense of vision, with the further amplification of this perception by means of somesthetic sensibility to the effect that the object is made of wood, becomes still more concrete as the result of the auditory process by which the object is named "a black wooden cube." The assignment of a name to the object depends primarily upon the sense of hearing and the appreciation of appropriate sound combinations.

The portion of the intermediate temporal area which surrounds the

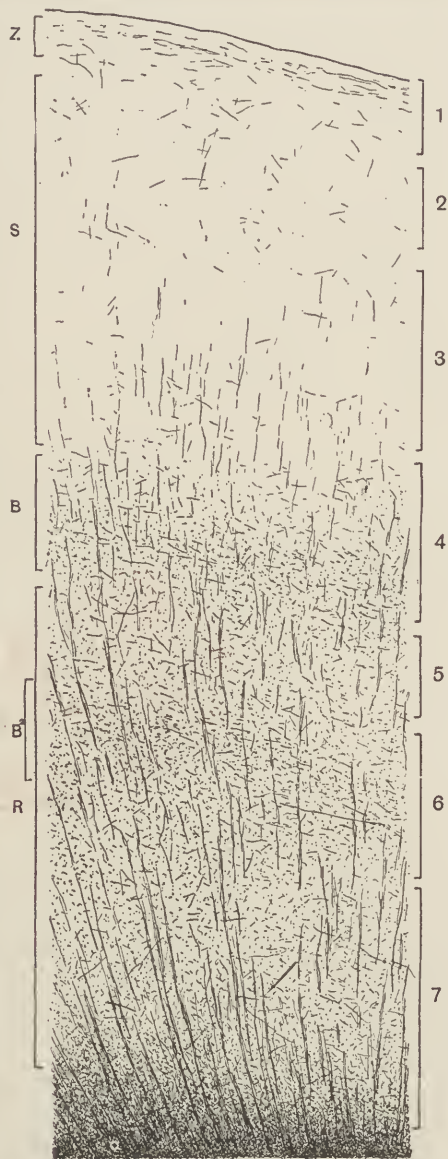


FIG. 558.—Stratigraphic analysis of the fibers in the parietal area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. B2—Reduplicated layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

upturned end of the Sylvian fissure, the *angular gyrus*, has been regarded as the *reading center*. Reported cases of lesions in it, on the left side in right-handed individuals, are said to produce an inability to read printed or written words, although other parts of speech remain intact. This condition is called *alexia*. Reading is dependent upon combination of the visual and auditory impressions. Tactile and muscle-joint sensations may to some extent enter into its essential syntheses. Fundamentally, this combination of the sensory impressions which makes reading possible is an integral portion of the psychic activities resulting in concrete ideas. The recognition of a printed letter or printed symbol implies a previous auditory perception which has conveyed the meaning of this symbol. The appearance, therefore, of such a letter or symbol in visual consciousness together with its significance as acquired through auditory experience, creates an interpretation in the mind of a constant and concrete idea.

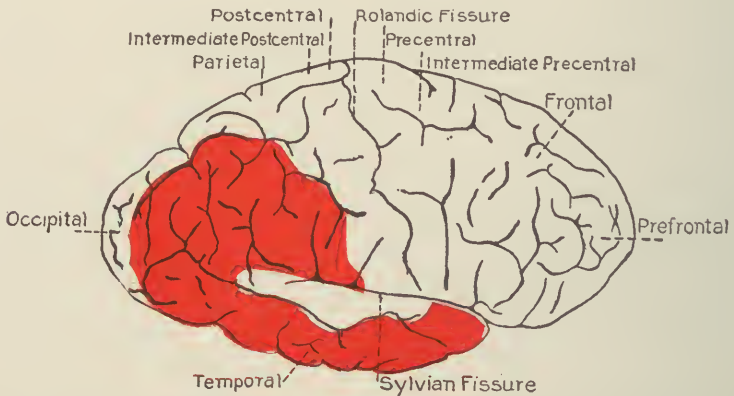


FIG. 559.—Cerebral cortex—lateral surface. Red indicates area for concrete conceptions.

In the process of learning to read, the child first learns the auditory perceptions of the different alphabetic characters. Subsequently, these auditory impressions are combined with the visual perceptions of the several characters so that the alphabetic symbols acquire names. In later development, these named symbols with their auditory associations are constructed into combinations forming words, each word having a different sound value and representing a concrete idea of its own. Reading, therefore, depends upon a combination of vision and hearing. The synthesis necessary to it, according to certain authorities, is carried on in the portion of the cortex covering the angular gyrus on the left side in right-handed individuals. On the other hand, those born blind may learn to read, but in this case the interpretation of characters and symbols is made through the tactile sense which furnishes perceptions of characters in bas-relief. In those born deaf, reading may be acquired solely through visual sensibility, but the more usual associations necessary to reading are vision and hearing.

In general, this extensive area situated between the temporal, postcentral and occipital areas may be provisionally regarded as a region of the

cortex in which concrete ideas are formulated by the combination of visual, auditory and somesthetic perceptions.

The Frontal Area. LANDMARKS, BOUNDARIES AND DISTRIBUTION. This area of the brain lies cephalad of the intermediate precentral area, the boundary line between the two being indefinite. On the lateral surface of the frontal lobe the caudal boundary of this area lies approximately 4.5 to 5 cm. in front of the Rolandic fissure. Its cephalic boundary extends from the vertex to the basal aspect of the lateral surface and may be represented by an irregular curved line averaging about 2 cm. caudal to the frontal pole. On the mesial surface the frontal cortex covers the small portion of the marginal gyrus corresponding to the area situated above the anterior half of the body of the corpus callosum and its genu. Its average width on the lateral surface is from 4.5 to 5 cm. Its greatest width is in relation with the middle frontal convolution, while it tapers gradually as it approaches and passes over the inferior frontal convolution in which region its dimensions are the smallest. Its average width on the mesial surface is 2.5 to 3 cm. The frontal area thus comprises the cortex covering the superior, middle and inferior frontal convolutions and the cephalic half of the marginal gyrus. It is contiguous caudally with the intermediate

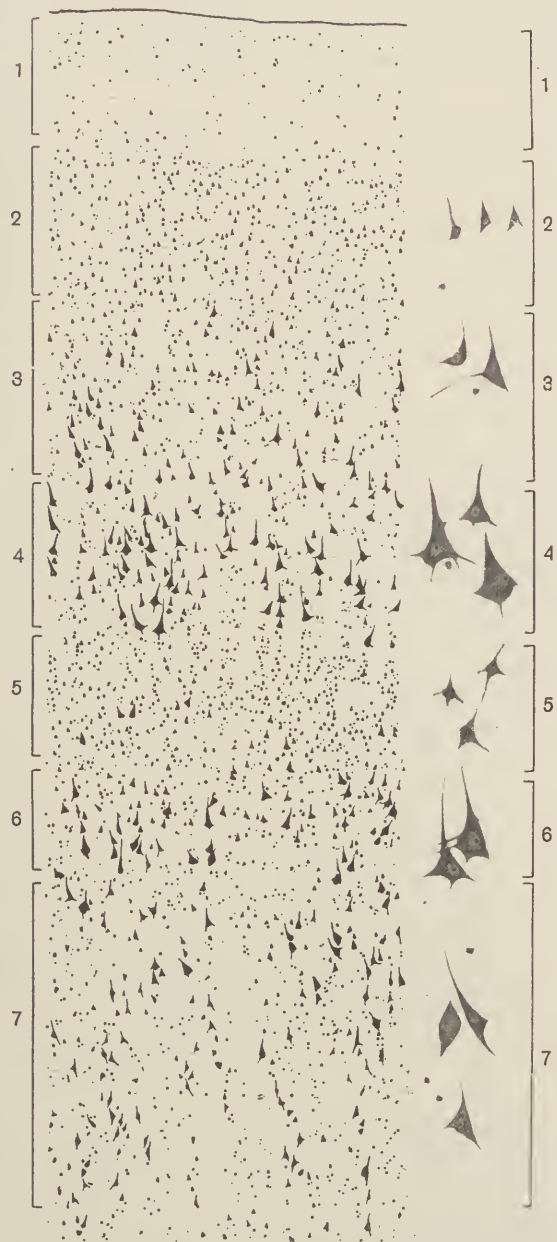


FIG. 560.—Stratigraphic analysis of the cells in the general temporal area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

precentral area, and cephalad with the prefrontal area. This type of cortex also appears upon the basal continuation of the three frontal convolutions on the orbital surface of the brain. On this orbital surface it covers a small area lying lateral to the external orbital sulcus and a narrow strip anterior to the *sulcus orbitalis transversus*.



FIG. 561.—Stratigraphic analysis of the fibers in the general temporal area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE FRONTAL AREA.
The Plexiform Layer. This stratum is not of service in the differentiation of the frontal area. In proceeding forward it tends gradually to lose in depth.

The Layer of Small Pyramidal Cells. This stratum shows no distinguishing features. The cells in it are numerous but scarcely more so than in other parts.

The Layer of Medium-Sized Pyramidal Cells. This stratum presents an arrangement in its cells that follows closely in detail that of other areas. The layer is of about equal depth with the adjacent zones. Its ectal and ental boundaries are indefinite and the layer as a whole becomes reduced in size when passing toward the prefrontal area.

The Layer of External Large Pyramidal Cells. The characters of this stratum constitute the chief features of differentiation. The large pyriform cells with indistinct chromophilic bodies which serve as one of the identification marks of the intermediate precentral area, become reduced in size and number on passing into the confines of the frontal zone. The stratum is still well defined in the frontal area, but the reduction in the size of the cells at once denotes transition

from the intermediate precentral area. The addition to this layer of many small pyramidal cells is also one of the distinguishing features of the frontal area.

The Layer of Stellate Cells. This stratum shows a progressive increase in width and definition upon passing from the intermediate to the frontal and prefrontal areas. The cells are not so closely aggregated nor is their arrangement so distinctly columnar as in the parietal and temporal cortex.

However, the steady increase in this stratum may be regarded as one of the identifying features of the frontal area.

The Layer of Internal Large Pyramidal Cells. In this stratum there is a reduction in the size and number of the large pyramidal elements much

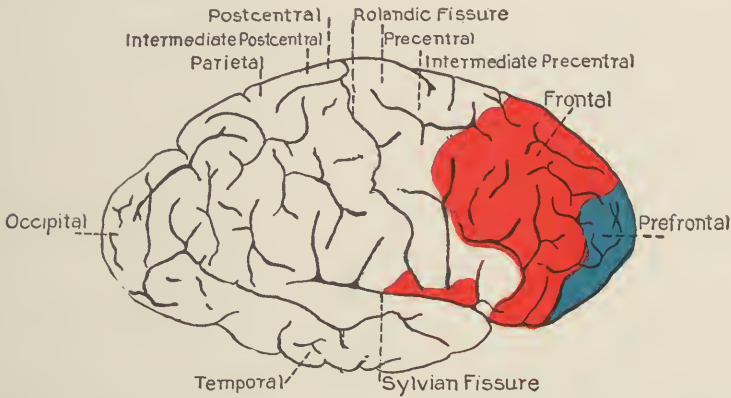


FIG. 562.—Cerebral cortex—lateral surface. Red indicates frontal area. Blue indicates prefrontal area.

the same as that observed in the layer of external large pyramidal cells. There is also a progressive decrease both in volume and in number in passing from the precentral toward the prefrontal area.

The Layer of Fusiform Cells. The fusiform layer, although present, is much reduced in width and becomes progressively less conspicuous in passing toward the prefrontal area.

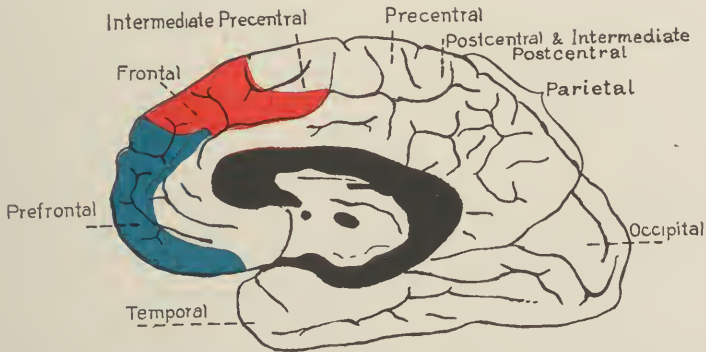


FIG. 563.—Cerebral cortex—mesial surface. Red indicates frontal area. Blue indicate prefrontal area.

STRATIGRAPHICAL DESCRIPTION OF THE FIBERS IN THE FRONTAL AREA.
The Zonal Layer. This layer which in the intermediate precentral area is conspicuous because of its great richness in fibers, stands in marked contrast to the frontal area because of the decrease in the number of fibers as well as the disappearance of the large varicose axones.

The Supraradiary Layer. This layer is likewise poorly represented in

fibers when compared with the intermediate precentral. Many long ascending fibers of Martinotti, however, and horizontal association fibers of medium size pass through this layer.

The Layer of Baillarger.

This layer is visible to the unaided eye, but on microscopic examination its fiber representation is distinctly less than that of the intermediate precentral area. There is no line of reduplication in the layer of Baillarger.

The Layer of Radiations—Radiary Layer. In this stratum the radiations of Meynert show a distinct attenuation in the size of the individual bundles as well as in the size of the constituent fibers. The change from the intermediate precentral area is so striking in this respect that the feebly developed state of the radiations of Meynert serves as one of the distinguishing features of this area. The interradiary plexus and association fibers show a marked reduction in size and number of the constituent fibers. Some medium-sized fibers with marked varicosities are present.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES OF THE FRONTAL AREA. The histological elements of the frontal area collectively represent a diminution in the size and number of the constituent elements. This reduction is especially conspicuous in:

1. The decrease in number and size of the elements entering into the layer of external large pyramidal cells.

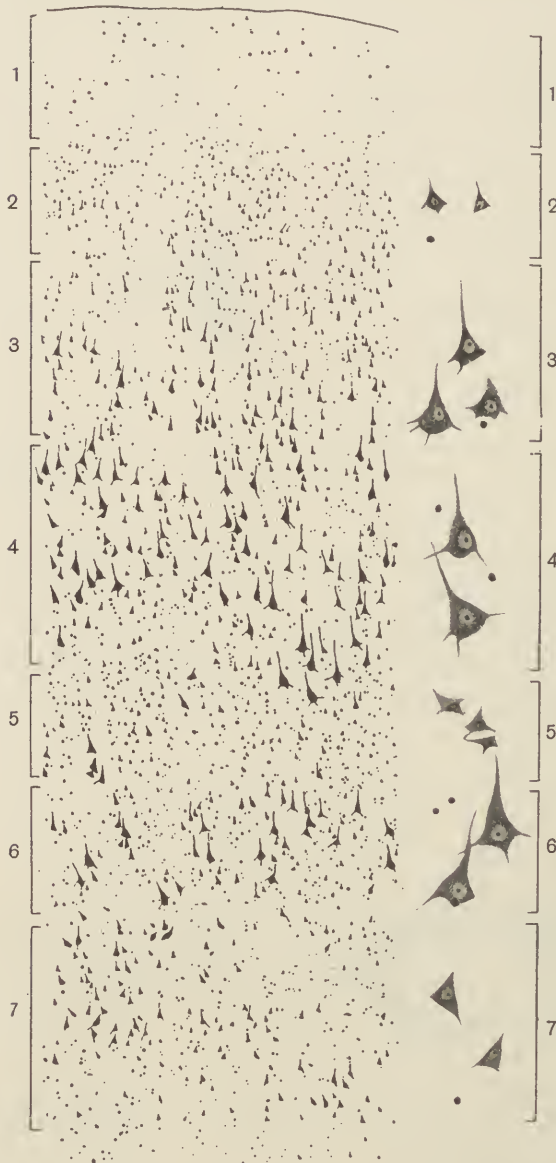


FIG. 564.—Stratigraphic analysis of the cells in the frontal area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

2. A similar reduction in the elements of the layer of internal large pyramidal cells.

3. The general decrease in prominence and in size of the constituent fibers of the line of Baillarger, the radiations of Meynert, the interradiary plexus and the association fibers.

4. The gradual increase in width and definition of the stellate layer of cells.

The Prefrontal Area. LANDMARKS, BOUNDARIES AND DISTRIBUTION. The area of the frontal lobe not covered by the frontal cortical type comprises a zone known as the *prefrontal area*. On the lateral and polar surface of the hemisphere this field is small and occupies only the most cephalic portion of the middle frontal convolution. On the mesial surface of the hemisphere it includes the portion of the marginal gyrus lying cephalad and ventral to the genu of the corpus callosum and also ventral to the prelimbic division of the calloso-marginal gyrus. On the orbital surface it is most extensive, covering all of the area with the exception of that caudal to the sulcus orbitalis transversus and lateral to the external sulcus.

STRATIGRAPHIC DESCRIPTION OF THE CELLS IN THE PREFRONTAL AREA. This area of cortex shows little to differentiate it from the frontal area in the *plexiform layer*, the *layer of small pyramidal cells* or the *layer of medium-sized pyramidal cells*.

In the *layer of external large pyramidal cells*, the cellular elements become elongated and pyramidal in form. Their chromophilic substance is difficult to distinguish and they undergo a marked reduction in number. The stratum as a whole decreases in width and is far inferior in its representation to other parts of the cortex.

The *layer of stellate cells* shows a decrease in width as compared with the frontal area.

The *layer of internal large pyramidal cells* shows a marked decrease



FIG. 565.—Stratigraphic analysis of the fibers in the frontal area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

both in size and in the number of the larger cells entering into this stratum. There is also a marked decrease in the medium-sized pyramidal cells.

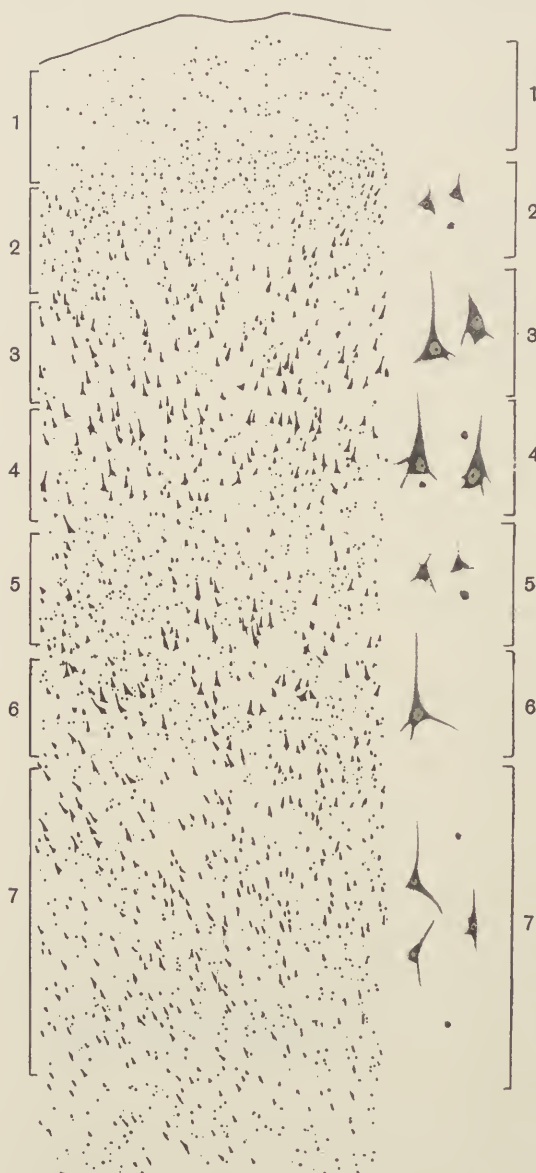


FIG. 566.—Stratigraphic analysis of the cells in the prefrontal area. (Campbell.)

1. Plexiform layer. 2. Layer of small pyramidal cells. 3. Layer of medium-sized pyramidal cells. 4. Layer of external large pyramidal cells. 5. Layer of stellate cells. 6. Layer of internal large pyramidal cells. 7. Layer of fusiform cells.

The *layer of fusiform cells* is narrow and contains many scattered, small cellular elements of this type.

STRATIGRAPHIC DESCRIPTION OF THE FIBERS IN THE PREFRONTAL AREA. The *Zonal Layer*. This stratum is very poorly represented in this area and contains but a few fibrils to indicate the existence of the layer at all.

The Supraradiary Layer. This stratum contains a few irregular scattered fibers. Its fiber representation in the outer portions is less than that in the inner parts of the stratum.

The Layer of Baillarger. This stratum is apparent to the unaided eye but more difficult to delimit microscopically. It is less prominent than in the frontal area.

The Layer of Radiations—Radiary Layer. The radiations of Meynert are much reduced in prominence in the prefrontal area. The large and medium-sized fibers have disappeared from the fasciculi which consist of delicate varicose elements. The interradiary plexus and association fibers are reduced in their general density and number and contain no fibers of large character.

SUMMARY OF THE CHIEF STRATIGRAPHICAL FEATURES OF THE PREFRONTAL AREA.

The prefrontal area presents a striking likeness to the frontal area, its chief differences being:

1. The marked reduction in the size and number of the larger elements in the layers of external and internal large pyramidal cells.

2. The absence of fibers of large caliber in the interradiary plexus and association fibers and radiations of Meynert.

3. The reduction of the zonal layer to a mere vestige as compared with this zone in other regions.

FUNCTIONAL SIGNIFICANCE OF THE FRONTAL AND PREFRONTAL AREAS. In general, the activities of the higher psychic faculties are attributed to the frontal and prefrontal areas. This definition of function implies much but specifies little. It leaves the significance of the higher psychic faculties entirely to imagination or individual predilection. It would seem impossible and perhaps ill-advised in this connection to consider any of the great volume of philosophic thought which has been devoted to this subject. Perhaps it may serve our purposes most advantageously to investigate this large region in the human brain long known as the *silent area*, by the direct and practical approach of clinical experience. It is of little profit to rehearse the many theories of consciousness and its origin when what we primarily seek is such enlightenment as will make clear the clinical manifestations resulting from disease or injury in this part of the brain.

So far as it is possible to ascertain at present, all areas of the brain outside of the frontal lobe are purely cognitive in their activity. Through their agency knowledge of the external world is acquired. This knowledge arises first as sensation in some quality of sensibility which may be visual, auditory, somesthetic, gustatory or olfactory. The sensation then becomes elaborated as a perception and finally acquires such associational values as make it a cognition correlated with previous similar experiences and differentiated from dissimilar experiences in its own sphere. A visual sensation in this manner becomes a visual perception. The perceptual character is ultimately extended by means of association until the perception becomes a visual cognition and the individual has knowledge through the sense of vision

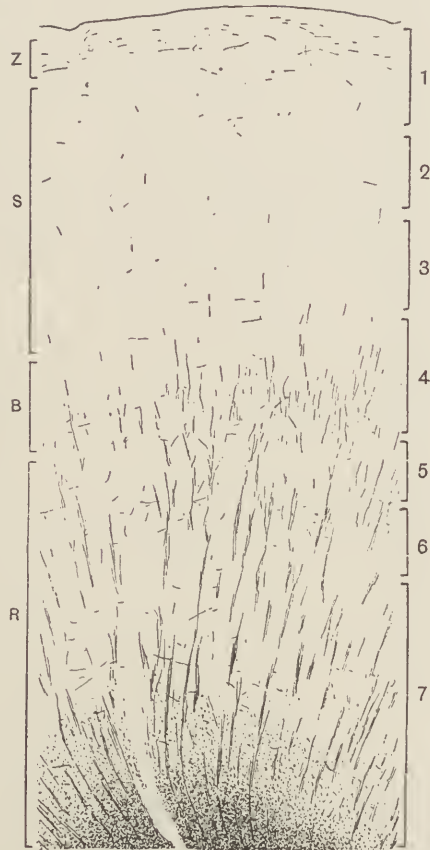


FIG. 567.—Stratigraphic analysis of the fibers in the prefrontal area. (Campbell.)

Z—Zonal layer. S—Supraradiary layer. B—Layer of Baillarger. R—Radiary layer. The numerals indicate positions corresponding to the seven cellular layers of the cortex.

of an object upon which he may gaze. Even the combination of several qualities of sensibility, such as vision and hearing, or vision, hearing and body sense, has as its end result the construction of more or less complex cognitions, all eventuating in a knowledge of external things. This knowledge, derived by means of any one of the senses or by several of them cooperating simultaneously, is quite devoid of any feeling or affect quality. The perception and recognition of an object may be complete, but this fact in itself does not imply any reaction toward the object. Thus, for example, the mere seeing of food and the recognition of its character as such by every possible sense, sight, smell and touch, is not sufficient to incite the animal to procure the food. The feeling of hunger must also be present. This feeling combined with the recognition of the object causes the animal to obtain its food. The performance of securing nutritive material would in this light appear to be dependent upon two factors, neither acting independently, but both combined to furnish the impulse and direction of the motor acts necessary to the performance. This combination may, for convenience, be termed the *motor incentive synthesis*, which in its simplest form, as already illustrated, consists of an element arising from the feeling of hunger and an element of recognition indicating the position and the character of the object sought as food. It is the combination of the affective (feeling) and the cognitive (knowing) that determines conation (volitional effort) as shown in the vast majority of voluntary acts whose purpose is the maintenance of the sense of well-being. For if the animal feeling hunger and seeing food is unable to obtain it for any reason, there arises a sense of unsatisfaction whose ultimate effect is to cause disturbance in the general sense of well-being.

It is probable that every object, the essence of which is acquired by the process of cognition, has attached to it some affective value. For the object either proves attractive to the individual or is repulsive. In any event, the mere object deprived of this affective element, or coloring of feeling tone, would be a matter of indifference in so far as any reaction on the part of the individual might be concerned. The infant seeing a brightly colored object and recognizing it as something outside of itself, may or may not make the effort to obtain it. But recognizing this brightly colored object as a ball which has attracted it before and with which it has been amused, the infant, unless some conflicting current intervenes, will invariably attempt to gain possession of the object. The same also applies to the flame of a candle whose bright color at first impels the infant to grasp the light. But having learned by experience that contact with this object causes pain, the recognition of it again results in a certain degree of repulsion and thus determines an inhibition in the movements which formerly were made to take hold of the flame.

In the evolution of the cognitive processes by which the horizon of individual knowledge is determined, a corresponding current of feeling-tone runs parallel with the acquisition of the cognition of all objects. In every conative reaction, in every effort guided by the will, these two streams of psychic activity meet and blend before action is consummated. *Knowing*

must be activated by *feeling* before volitional reaction occurs. To provide the means for blending the cognitions of vision, hearing, body sensibility, smell and taste with the primitive incentive feelings such as those of hunger, sex, fear, anger, parental possession, etc., would not necessarily require a complex mechanism and the motor incentive synthesis arising from such combination would be correspondingly simple. But when these elements of feeling-tone become more complex, as, for example, in the binary and tertiary combinations of the primary feelings such as loathing, contempt, scorn, hate, fascination, wonder and admiration, there has occurred a great expansion in the sphere of feeling-tone which is apparent only in the case of man. Cognition has become correspondingly expanded, so that the combinations of knowing and feeling are infinitely multiplied and the incentive syntheses are correspondingly complex.

If search were made among the various areas of the brain to determine the most likely place for the elaboration of these complex syntheses, the frontal lobe would doubtless be selected as best fitted for such a process. Here, at least, is an area into which impulses may make their way from the visual region, the auditory region, the somesthetic region, the gustatory and the olfactory regions. But in addition to providing a means for combining all of the different impulses derived from these various sources of cognitive activity, the frontal lobe receives a rich contribution of nerve fibers from the optic thalamus. It is generally believed that the thalamus is the site of the primary emotions and acts as that part of the brain primordially concerned in feeling tone. The connection between the thalamus and the frontal lobe has been explained as providing for a manifold expansion of primary feeling-tone into the more complex binary and tertiary emotions and ultimately the still more complex sentiments. Nowhere else in the brain, apparently, is provision made for such syntheses as would afford opportunity for combining knowing with feeling. The direct results of these incentive syntheses are manifest in behavioral reactions, all of which appear ultimately to be directed to the maintenance of the sense of well-being.

But cognition through the senses is not the only knowledge that we come to possess. By introspection we gain a knowledge of self, a knowledge known as *self-consciousness*. This is a process by which we distinguish between our empirical self and what is not self. It gives rise to an appreciation of the ego as distinct and apart from other material facts. In its inception, this distinction first determines a definition between the ego and other persons. This is true of the infant, in whom the primitive distinction between itself and other objects is a differentiation between itself and other persons. Later the distinction extends to objects other than persons, and so the differentiation between the ego and all other material things is gradually expanded. Finally, as a result of self-consciousness, personal relations are recognized and understood. Eventually by a process of trial and error, social and moral laws are comprehended. According to McDougall, in the development of each individual, quite as much as in the course of development of every race, certain stages must be traversed before that highest

plane of moral understanding is attained. In their order of succession these stages are:

The stage of instinctive behavior modified by the influence of pains and pleasures, incidentally experienced in the course of instinctive activities.

The stage in which the operation of instinctive impulses is modified by the influence of rewards and punishments administered by social environment.

The stage in which conduct is controlled in the man by the anticipation of social praise and blame.

The highest stage, in which conduct is regulated by an ideal of behavior which enables the individual to act in a way that seems to him right regardless of the praise or blame of his immediate social environment.

Not only is an understanding of the social and moral law acquired by means of introspection and the development of self-consciousness, but the laws governing inanimate objects are also perceived and understood by a process growing out of such introspection. This process depends upon the sustained contemplation of self and the content of cognitions in their relations to the *extra-self* which leads to the psychic process called thought. Thought, as a process, according to Strong, is a sort of "anticipatory vision as vision is a sort of anticipatory touch. It represents an essential, although somewhat less secure, enlargement of the area of cognition. As touch permits us to recognize only objects with which we are in actual contact, so vision, showing us things at a distance, vastly extends the range of possible adjustment. It is sort of a long distance touch with the advantage that we can touch the object, as, for example, a wild beast, without its touching us. The senses, however, only reveal the things that are near to us in space and simultaneous with us in time. Thought looks before and after. It permits adjustment to objects while they are yet unseen, to events in advance of their occurrence."

The correlation of thoughts concerning closely related subjects and objects, results in reason, the complexity of which depends directly upon the richness of thought processes. Out of the power of reasoning develops judgment. Thought also is the basis of imagination; and all these play essential parts in the constitution of the higher psychic faculties.

Regardless of the degree to which any of these processes, tentatively attributed to the activity of the frontal lobe, may be developed, it is certain that all of them contribute to the formation of the motor incentive syntheses which determine the behavioral reaction of the individual. The part played in such syntheses by cognition and feeling-tone, as well as by conscious adaptation to social environment, has already been discussed. It is not difficult to appreciate how thought, reason, judgment and imagination enter into the formation of these syntheses, influencing their composition and aiding to cast the mould of the behavioral reactions which serve as the chief distinguishing mark of the individual. The retention of all of these psychic elements in memory contributes to the upbuilding of a generalized experience out of which grows an intangible yet indubitable quality characteristic of each individual, personality.

Personality includes the recognition in experience of past behavioral reaction. The behavior of any individual is determined by all the elements which enter into the constitution of personality. The degree of richness of cognition, the sensitiveness of feeling-tone, the dominance of thought, reason, judgment and imagination, all contribute their part to the syntheses which determine the manner in which the individual reacts to his environment. Defects in cognition restrict or produce defects in behavior. Disturbances in feeling-tone cause reactions of undue emotional force or of emotive expression above or below the limits of what is deemed normal. Defects in the process of thought give rise to serious disorders of cerebration with corresponding imperfections in social adjustment or behavioral reaction. Defects in reason and judgment lead to irrelevancies and other disturbances of action; while the imagination may be involved in such way as to produce marked changes in behavior. Personality has its expression, therefore, in behavior which indicates the reaction of the individual to his environment. Changes in personality determine alterations in behavior.

Syndromes of the Frontal and Prefrontal Areas. It was long considered that the region of the brain known as the *silent area* yielded no clinical evidence when injured or diseased. An important step toward the recognition of the symptoms due to trauma of the frontal area came from the remarkable case of Phineas P. Gage. This man, a laborer, was injured in 1848 by an explosion as a result of which a crowbar was driven directly through the left orbit into and through the left frontal lobe. The patient survived this injury for many years. As the lesion in his brain produced an extensive destruction of the frontal lobe upon the left side, it furnished an opportunity to note the clinical changes due to this disturbance. These changes were confined to what has been spoken of in general terms as the higher psychic faculties. The patient's judgment and reason were both impaired and his personality manifested marked alterations. His temper became fitful and he was subject to sudden, often unprovoked outbursts of rage; his moods were vacillating; he sought and filled many different positions; his steady habits gave place to aimless wanderings and sometimes grandiose adventures. He carried the bar which caused his injury about with him and exhibited himself in many large cities. His social attitude was greatly altered. His transactions were often dishonest and his language became extremely profane, though it was never so before his accident. In a word, his personality was converted by the injury to his brain from that of an active, steady and alert workman, to that of a restless, adventurous and unreliable member of society. Following several severe convulsions he died in 1861, twelve and a half years after his accident. The cranium, together with the crowbar which caused the injury, are in the Warren Anatomical Museum, Harvard University. (Specimen No. 949.)

Many later clinical observations have strengthened the conviction that the frontal and prefrontal areas are vested with those functions of cerebral activity necessary to development of the psychic traits which distinguish man among the other animals.

Slowly developing lesions in the frontal and prefrontal areas will cause a gradual separation or distortion of the two concurrent streams in consciousness, knowing and feeling, so that the patient no longer attaches the proper feeling-tone to his recognitions. Such, for example, is the case in paresis in which the lesion usually affects the frontal area, causing a gradual atrophy of the frontal convolutions. Usually the patient suffers from a more or less marked *euphoria* (exaltation in the sense of well-being). If asked how he feels he replies that he never felt better in his life. Everything on his horizon undergoes a marked expansion. He believes he is the wealthiest, the most powerful and the most capable person living. He is not able to correct this misapprehension by introspection or recognition of the objects about him. This disproportion of the normal concurrence in the affective and cognitive streams of consciousness seems to be due to disease in the frontal area. It may, however, be the case that the splitting off of these two elements from each other will result in extreme depression, and that elements in the environment which should normally produce nodepressing effect, cause sustained and profound dejection.

Irritative lesions, such as a focal frontal lobe meningitis, lead to marked emotional excitation with pressure of activity, delirium and mania. The patient may scream, thrash about, attack those near him, and give every evidence of extreme emotional excitement. If the character of the lesion is less intense and less acute, reason, judgment and insight become defective. The patient suffers from delusions which are falsified beliefs so firmly fixed that no argument to the contrary can convince him of their inaccuracy. Practically all of these delusions center in self-consciousness. They may be systematized and persistent or unsystematized, changeable and fleeting. These delusions may be apprehensive, nihilistic, expansive, accusatory, persecutory, delusions of jealousy, delusions of mysterious power due to some magical, telepathic, sexual or supernatural influence. Controlled by such delusions, the behavioral reactions become markedly changed and often anti-social. Dependent upon the degree of delusional dominance, the acts become irrelevant and the whole process of thought illogical. In some instances consciousness is more profoundly affected. The patient falls into a profound sleep or lies in stupor or in coma. When less seriously involved, consciousness is befogged, giving rise to confusional states in which the patient seems dazed and incapable of making proper psychic contact with reality or of properly comprehending his own psychic states. As a result of these changes, the entire composition of personality is altered and the individual presents such modifications in his normal incentive syntheses that he is no longer recognizable as the same person by those associated with him.

Brain tumors involving the prefrontal and frontal areas on the left side in right-handed individuals produce a marked change in personality which either reveals itself as an exaltation in the sense of well-being, somewhat resembling the euphoria of the parietic, or leads to apathy, indifference and sullenness. The gradual development of these changes in personality is one

of the most significant indications of neoplasm in the frontal lobe, especially when attended by the signs of generally increased intracranial pressure. Such changes should always arouse suspicion of the possibility of involvement in this area.

Tumors of the prefrontal and frontal areas in their inception often declare themselves as a slight change in personality. The patient may develop an undue levity, persist in more or less senseless joking and act in a manner which for him is undignified and out of keeping with his character as understood by his associates. This condition is spoken of as *prankishness* ("witzelsucht").

Less frequently tumors in the frontal lobe give rise to depressive manifestations, slight lapses in memory, attacks resembling petit mal (momentary loss of consciousness), a sense of unreality or a psychic micropia which gives the patient the impression that all things about him are far away and very small. This, in effect, is a failure of mental perspective. Usually with this condition there is a marked increase in feeling-tone and the patient is prone to sudden outbursts of emotion.

The general effects of these changes in consciousness which produce such pronounced alterations in personality, have their outward expression in behavioral reactions and conduct. A number of such disorders in behavior have already been identified in connection with lesions of the frontal lobe. These disturbances collectively constitute pathological conduct. They consist of stereotyped, manneristic and compulsive reactions, impulsive and perverted reactions, contra-social conduct resulting in indecencies and improper exposures, morbid swindling and lying, pyromania, kleptomania, contra-sexual conduct such as sadism (sexual excitement increased by brutality), masochism (sexual excitement increased by the endurance of pain), changes of conduct due to delusions of self-depreciation causing abnormal acts of penance, self mutilation and suicide, delusions of persecution and jealousy causing reactions of misanthropic isolation, outbursts of rage and homicidal attacks; irrelevant reactions which seem to arise spontaneously without a proper correlation of the acts to the time or place which normally conditions such reactions.

In summary, disease or injury of the frontal lobe produces changes in personality by disturbing one or more of the constant psychic elements entering into that composite and manifest expression of consciousness which makes us so similar as a species and yet so strikingly different as individuals.

CHAPTER I

THE ENDBRAIN

THE INTERNAL STRUCTURE OF THE HEMISPHERE AND THE VENTRICULAR SYSTEM

In order to obtain an adequate conception of the internal structure of the hemisphere, it is necessary to study sections in several planes. The horizontal and coronal planes are the most satisfactory for such purposes. The horizontal plane is parallel with the base line of the skull; the coronal plane is taken at right angles to the base line.

A SERIES OF SECTIONS MADE IN THE HORIZONTAL PLANE

The following horizontal sections were made by means of the macrotome. The relations of the cortex, medullary substance, basal ganglia, internal capsule, lateral ventricle and thalamus may easily be appreciated in them.

Immediately Beneath the Vertex of the Hemisphere. In this section the cortex of the frontal and parietal lobe appears as a marginal band surrounding the medullary substance and insinuating itself into many deep irregular fissures. One deep annectant gyrus occurs in the parietal region. A long irregular streak of gray matter extends into the medullary substance for a considerable distance. This represents the cortex at the depth of the superior frontal convolution. The dorsal extremity of the fissure of Rolando and a horizontal portion of the intraparietal fissure are also shown (Fig. 568).

Through the Dorsal Portion of the Centrum Ovale. At this level the cortex shows its usual disposition as a marginal band investing the several convolutions on the mesial and lateral surfaces of the hemisphere. The *centrum ovale* comprises the large mass of medullary substance situated in the center of the section from which massive prolongations extend into each convolution. These extensions represent the fiber elements forming the *corona radiata*. Those fibers arising or terminating in the mesial convolution constitute the *mesial lamina* of the coronal rays, while the fibers bearing similar relation to the convolutions on the lateral surface represent the *lateral lamina*. (Fig. 569.)

The cortex manifests some alteration especially upon the mesial surface. In other areas it presents itself as the sinuous gray band seen at other levels. Upon the mesial surface, particularly in the middle half, there is a distinct thinning of the cortical substance as well as a disappearance of the convolutions. This area which is about to disappear with the advent of the callosal fibers into the medullary substance represents the zone immediately above the corpus callosum. Immediately in front and behind this attenuated strip

of cortex the convolutions reestablish themselves on the mesial surface in their usual prominence. The centrum ovale has reached its greatest dimensions. The lateral and mesial laminae of the corona radiata may be observed in the frontal and occipital region of this section.

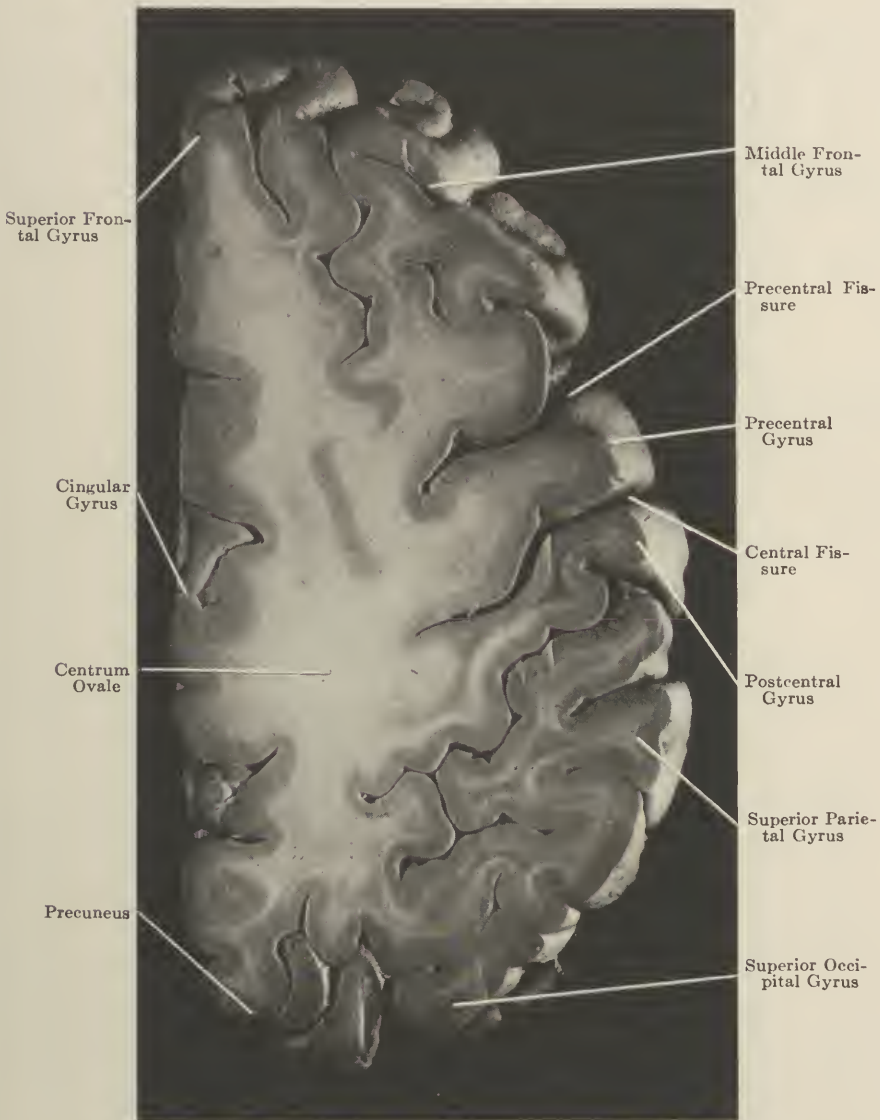


FIG. 568.—Horizontal section of hemisphere beneath the vertex.

Through the Level of the Corpus Callosum and the Body of the Lateral Ventricle. In this section the fibers of the corpus callosum have penetrated the mesial surface of the hemisphere and appear as transversely crossing fibers. The locus of their entry into the hemisphere is marked by an area in which

the cortex has disappeared. This area varies from 1 to $1\frac{1}{2}$ inches in length. The adjacent cortex is much attenuated both in front and behind, but the

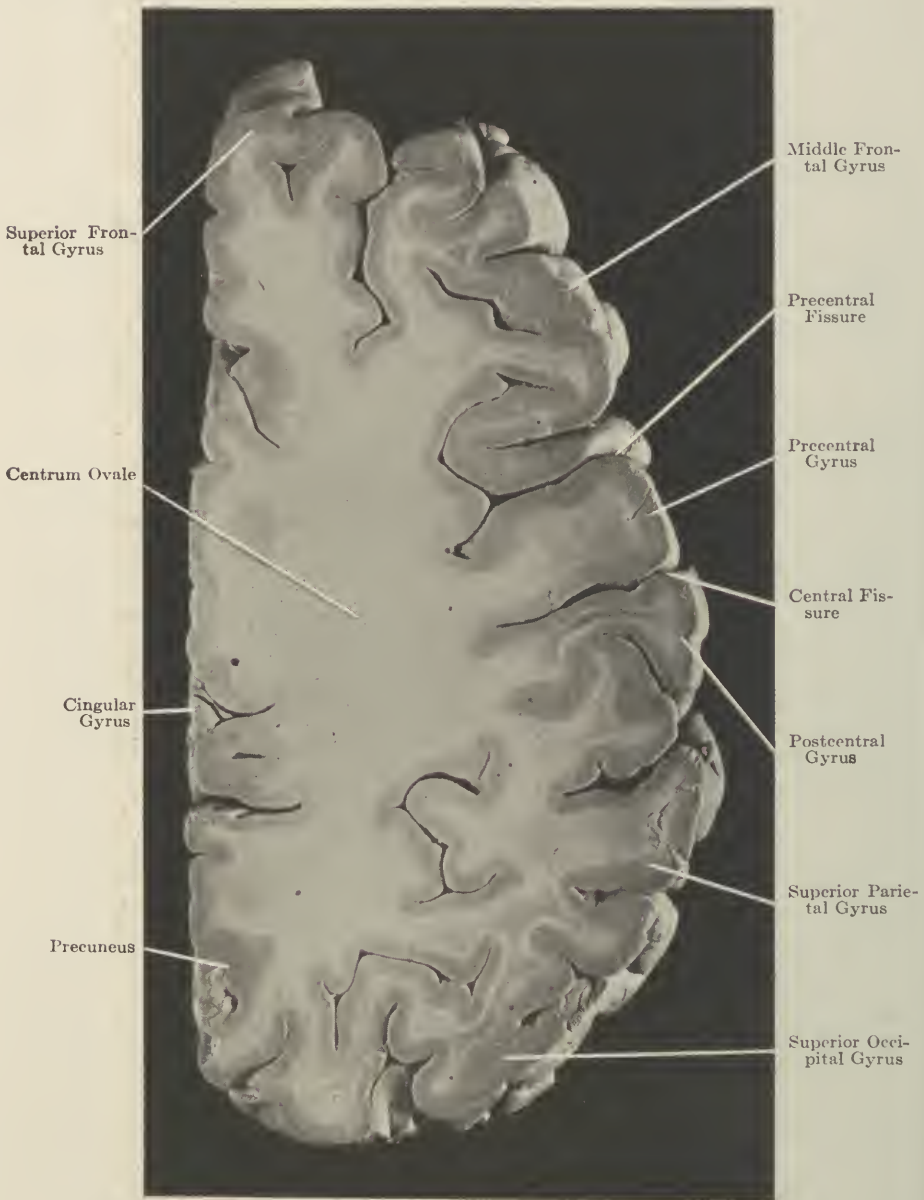


FIG. 569.—Horizontal section of the hemisphere through the centrum ovale.

cortical substance reasserts itself upon the mesial surface of the frontal and occipital poles in its usual prominence. On the lateral surface the convolutions appear giving an unusual richness to the cortex. Midway between the

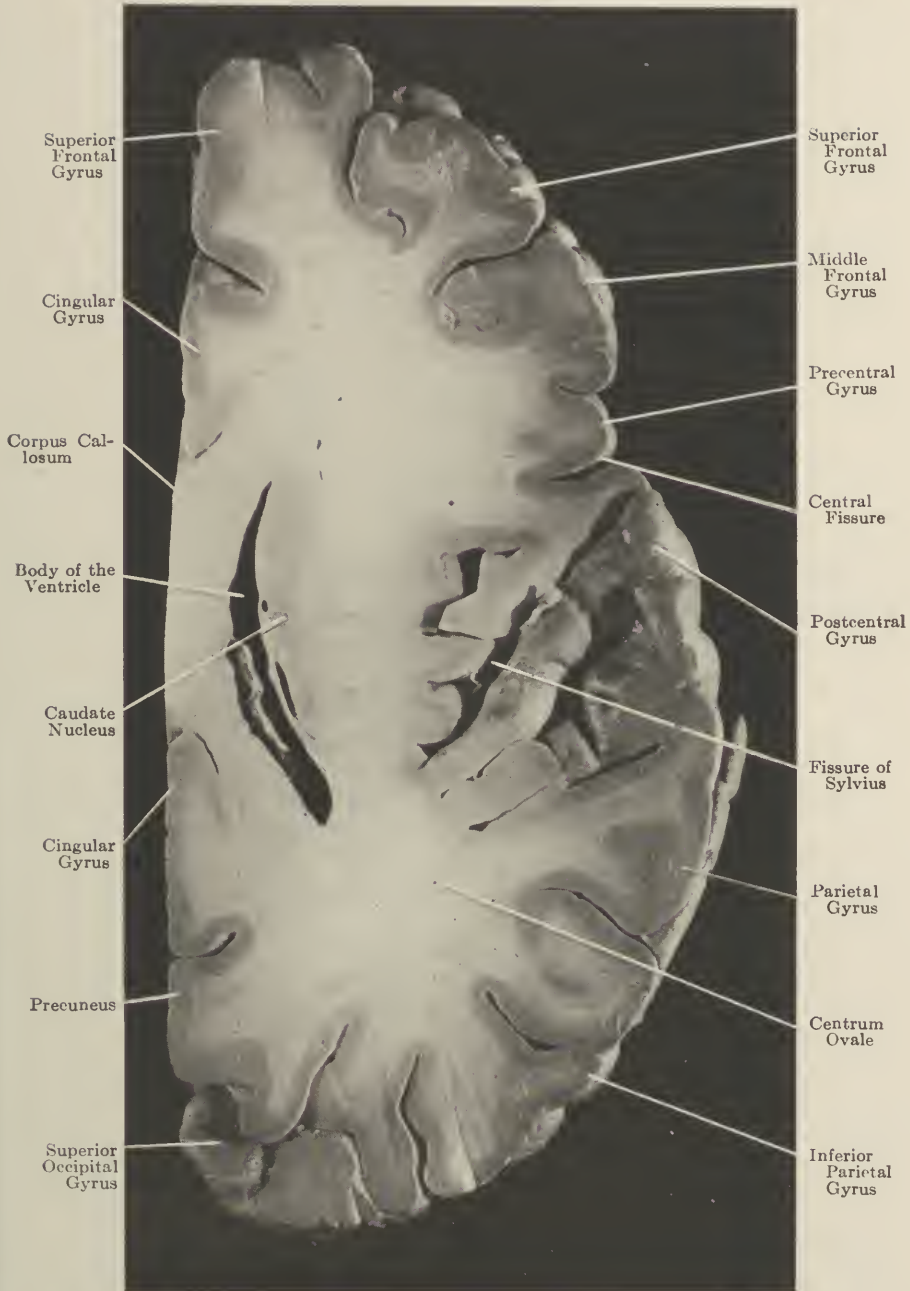


FIG. 570.—Horizontal section of the hemisphere through the body of the corpus callosum.

occipital and frontal poles the horizontal limb of the *fissure of Sylvius* makes its appearance. This section reveals a portion of the dorsal surface of the temporal lobe, showing two of the transverse gyri of Heschl. The medullary substance no longer presents itself as an unbroken mass extending from the lateral to the mesial cortex; it is interrupted in its middle by a long crescentic slit whose convexity is turned toward the lateral surface. This cavity is the body of the lateral ventricle. It is bounded mesially by the fibers of the corpus callosum and laterally by a mass of gray matter which constitutes the head, body and beginning of the tail of the caudate nucleus, the most recently acquired portion of the *neostriatum*. (Fig. 570.)

Through the Atrium and Frontal Cornu of the Lateral Ventricle.

In this section the cortex upon the lateral surface has its characteristic appearance with the added feature of the *island of Reil* exposed in the depths of the *Sylvian fossa*. Four distinct convolutions of the insula are present. The *line of Gennari* is visible in the occipital region. Upon the mesial surface the fibers of the genu and splenium of the corpus callosum, together with the *fornix* and *septum pellucidum*, separate the cephalic and caudal portions of the *limbus corticalis*. The medullary substance is much reduced in its dimensions due to the presence of the basal ganglia and the large cavities constituting the *frontal cornu* and *atrium* of the lateral ventricle. The mesial laminae of the corona radiata, in relation with the frontal and occipital lobes, make their way into the central mass of the medullary substance, while the lateral laminae of the coronal rays pass inward from the frontal, temporal, parietal, occipital and insular areas of the cortex. Mesially the fibers in the genu of the corpus callosum sweep forward and outward into the medullary substance of the frontal lobe, forming their respective portions of the *forceps minor*. The fibers in the splenium of the corpus callosum pass outward and backward in a much wider arc forming the right half of the *forceps major*. The mesial boundary of the frontal cornu is formed by an attenuated membranous structure containing some atrophic nerve cells and fibers, the *septum pellucidum*. This septum is in partial contact with its fellow of the opposite side, the space intervening between them forming the *cavum septi pellucidi*, which is sometimes spoken of as the *fifth ventricle*, but which is not in connection with the ventricular system. In the space intervening between the caudal extremity of the septum pellucidum and the cephalic extremity of the splenium of the corpus callosum is a massive bundle of medullary substance constituting the body of the *fornix*. Caudally, this structure is prolonged as the *fimbria* (also called the posterior pillars of the fornix) into the atrium of the lateral ventricle.

The Basal Ganglia, Thalamus and Capsules. Situated at about the center of the medullary substance and in close relation with the lateral ventricle, are several large masses of gray matter constituting the optic thalamus and corpus striatum. The corpus striatum at this level comprises the head of the caudate nucleus and the putamen of the lenticular nucleus as well as the claustrum and tail of the caudate nucleus. The head of the caudate nucleus projects into the frontal cornu of the lateral ventricle and constitutes

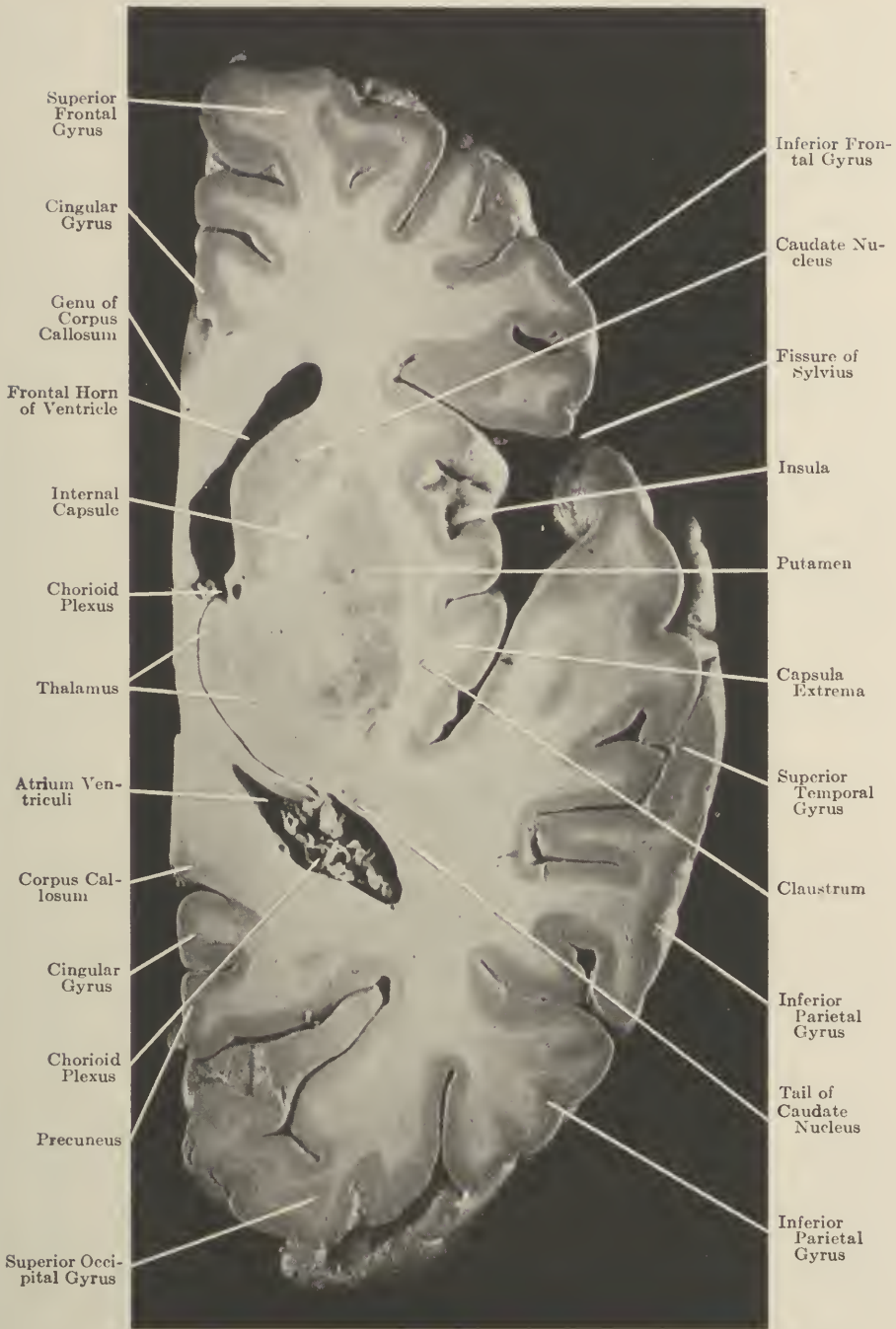


FIG. 571.—Horizontal section of the hemisphere through the atrium ventriculi.

the chief intraventricular portion of the corpus striatum. The putamen of the lenticular nucleus is separated from the head of the caudate nucleus and the optic thalamus by the massive bundle of fibers forming the lenticulo-caudate portion of the *internal capsule*. Lateral to the putamen is the narrow band of medullary substance, the *capsula externa*. A thin streak of gray matter parallel to the lateral surface of the putamen constitutes the *claustrum*. Situated between the island of Reil and the claustrum is a narrow band of medullary substance, the *capsula extrema*. The tail of the caudate nucleus is situated in relation with the lateral wall of the atrium of the lateral ventricle.

The optic thalamus occupies a position mesial to the fibers of the internal capsule and in close relation with the body of the lateral ventricle. At its cephalic extremity is the anterior thalamic nucleus caudal to which are the internal and mesial nuclei of the thalamus. The medullary laminae of the thalamus serve to establish the boundary line between these important nuclear centers.

The *internal capsule* presents itself as a dense and somewhat irregular mass of fibers bounded by the putamen laterally, and by the head of the caudate nucleus and optic thalamus mesially. It consists of many fibers running in an oblique direction toward the base of the brain, and numerous axones forming small fasciculi passing between the basal ganglia and the thalamus in a horizontal plane. This represents the upper thalamic portion of the internal capsule at a level in which the coronal rays are entering upon their final stage of collection to form the projection systems of the hemisphere. An anterior and a posterior limb of the capsule may be recognized with a more or less well defined genu between them. The anterior limb is situated between the head of the caudate nucleus and the putamen, the posterior limb between the optic thalamus and the putamen; and the genu is in relation with the point of approach between the head of the caudate nucleus and the thalamus. A distinct retrolenticular portion of the internal capsule is visible which separates the putamen from the tail of the caudate nucleus and passes in a wide arc backward into the occipital lobe. This is the beginning of the *optic radiation of Gratiolet*. The external and extreme capsules are differentiated by the presence between them of the claustrum. Their exact significance is not understood.

The lateral ventricle at this level consists of the frontal cornu whose cephalic boundary is the medullary substance. Its mesial boundary is the splenium of the corpus callosum and the septum pellucidum; the lateral boundary is the head of the caudate nucleus. A small canal represents the basal portion of the body of the ventricle which connects with a large chamber, the atrium ventriculi. The frontal cornu contains no chorioid plexus. A large mass of chorioidal glands appears in the atrium. These represent an extension of the chorioid plexus of the lateral ventricle. (Fig. 571.)

Through the Thalamic Portion of the Internal Capsule. In this section the general appearance of the cortex upon the lateral surface resembles that of the rest of the pallium. The island of Reil shows two marked convolutions converging toward the *limen insulae*. The island

itself is excluded from the surface of the brain by the frontal and temporal opercula which bound the Sylvian fissure. The line of Gennari is still visible in the occipital region and is especially prominent in the calcarine area. The first, second and third frontal convolutions are shown in transverse section at the frontal extremity of the brain, while the second temporal and parietal together with the first and second occipital and calcarine convolutions are shown at the occipital pole. The cephalic and caudal extremities of the *limbus corticalis* are now widely separated on the mesial surface, of which latter less than half is covered with cortex, due to the interposition of the corpus callosum and the fornix.

The medullary substance is much reduced in size, due to the increased dimensions of the basal ganglia and the thalamus. The splenium and genu of the corpus callosum still make extensive contributions to the medullary substance forming the forceps major and minor respectively. The greater part of the medullary substance of the hemisphere at this level lies in front and behind the basal ganglia. The anterior extremity of the body of the fornix and the anterior pillars of the fornix are caudal to the genu of the corpus callosum. Extending between the anterior pillars of the fornix and the genu of the corpus callosum is a membranous structure forming the mesial boundary of the lateral ventricle, the septum pellucidum. Between the two septa pellucida is a small slit-like cavity, the cavum septi pellucidi. This has no connection with the ventricular chambers of the endbrain.

Basal Ganglia, Thalamus and Capsules. The head of the caudate nucleus still bears its usual relation to the frontal cornu of the lateral ventricle. It has become somewhat reduced in size. The tail of the caudate nucleus is in relation with the cephalic wall of the temporal cornu of the lateral ventricle. The lenticular nucleus at this level shows its two major divisions, the putamen having much the same color as the head of the caudate nucleus, and a smaller triangular area much lighter in color, the *globus pallidus*. This latter structure represents the *paleostriatum*. The corpus striatum here presents all of its characteristic parts, namely, the caudate nucleus and the two divisions of the lenticular nucleus, the *globus pallidus* and putamen. The caudate nucleus and the putamen are phyletically closely related, representing recent additions to the striate body and constituting the *neostriatum*. The claustrum in this section is somewhat more prominent than in the higher planes, bearing the same relation here as at the higher levels to the lateral surface of the putamen and mesial surface of the island of Reil.

The thalamus consists of a mesial and lateral nucleus and the remainder of the anterior nucleus situated at its cephalic extremity. The lamina medullaris interna serves to separate the mesial nucleus from the lateral nucleus and in general establishes a boundary between the *neothalamus* and the *paleothalamus*.

Situated between the head of the caudate nucleus and thalamus on the one hand and the lenticular nucleus on the other is the dense collected mass of medullary fibers constituting the internal capsule. At this level the internal

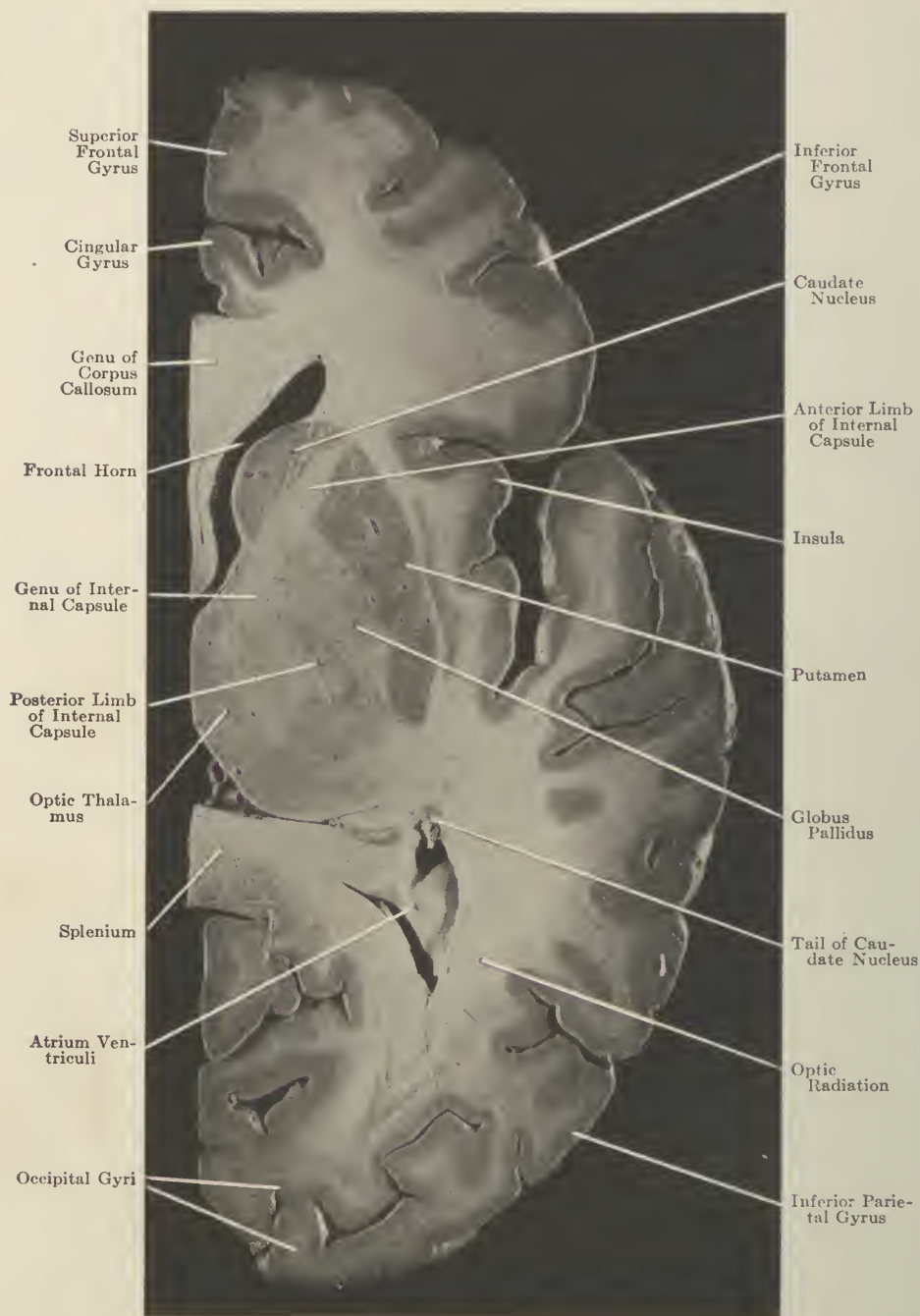


FIG. 572.—Horizontal section of hemisphere at the thalamic level of the internal capsule.

capsule consists of its three distinct parts, the anterior limb, the genu and the posterior limb. The anterior limb separates the head of the caudate nucleus from the lenticular nucleus. It is much lighter in color than the posterior limb and is made up of fibers which are seen to enter the thalamus. For the most part the fibers in the anterior limb of the internal capsule at the thalamic level consist of the thalamo-cortical and cortico-thalamic fibers constituting the *anterior thalamic peduncle*. The genu of the internal capsule is situated in relation to the apex of the lenticular nucleus and the junction of the head of the caudate nucleus with the thalamus. The posterior limb of the internal capsule separates the lenticular nucleus from the thalamus. Its darker appearance in contrast to the anterior limb is due to the fact that numerous bridges of gray matter extend between the globus pallidus and the lateral portion of the optic thalamus (*pontes grisei lenticulares*).

The external capsule separates the claustrum from the lateral surface of the putamen. The extreme capsule is interposed between the lateral surface of the claustrum and the cortex of the island of Reil. The ventricle at this level presents itself as a large cavity mesial to the head of the caudate nucleus, the frontal cornu; and also a large cavity in relation to the temporal lobe mesial to the fibers entering the medullary substance from the splenium, the temporal cornu. (Fig. 572.)

Through the Subthalamic Portion of the Internal Capsule and Anterior Commissure. In this section the cortex upon the lateral surface has its usual appearance. The island of Reil is much reduced in size but enlarges toward the limen insulæ. It is concealed from view by the overlying frontal and temporal opercula bounding the Sylvian fissure. The occipital cortex still shows the line of Gennari. The first, second and third frontal convolutions are shown transversely cut, also the first, second and third temporal convolutions and the first and second occipital and calcarine convolutions. The caudal portion of the limbus corticalis now forms the *subiculum*, the *cornu Ammonis* and the *gyrus dentatus* of the limbic lobe with the *gyrus cinguli* situated anterior to the fibers from the rostrum of the corpus callosum. The medullary substance has now somewhat greater dimensions than in the sections above, due to the reduction in size of the basal ganglia. The ventral rays of the corona radiata constituting the *laminæ medullares laterales* and *mediales* are now present in the frontal and occipital lobes. The fibers of the rostrum of the corpus callosum enter the medullary substance caudal to the cephalic portion of the limbus corticalis.

The anterior commissure enters the mesial surface of the hemisphere and passes transversely across the section to merge with the medullary substance. It makes its passage in a position approximately corresponding to the genu of the internal capsule.

The Basal Ganglia, Subthalamus and Capsules. At this level the head of the caudate nucleus, much reduced in size, lies surrounded by the medullary substance in a position immediately cephalic to the transverse fibers of the anterior commissure. It is in close relation with the putamen with which it is in part connected by means of bridges of gray matter. A few

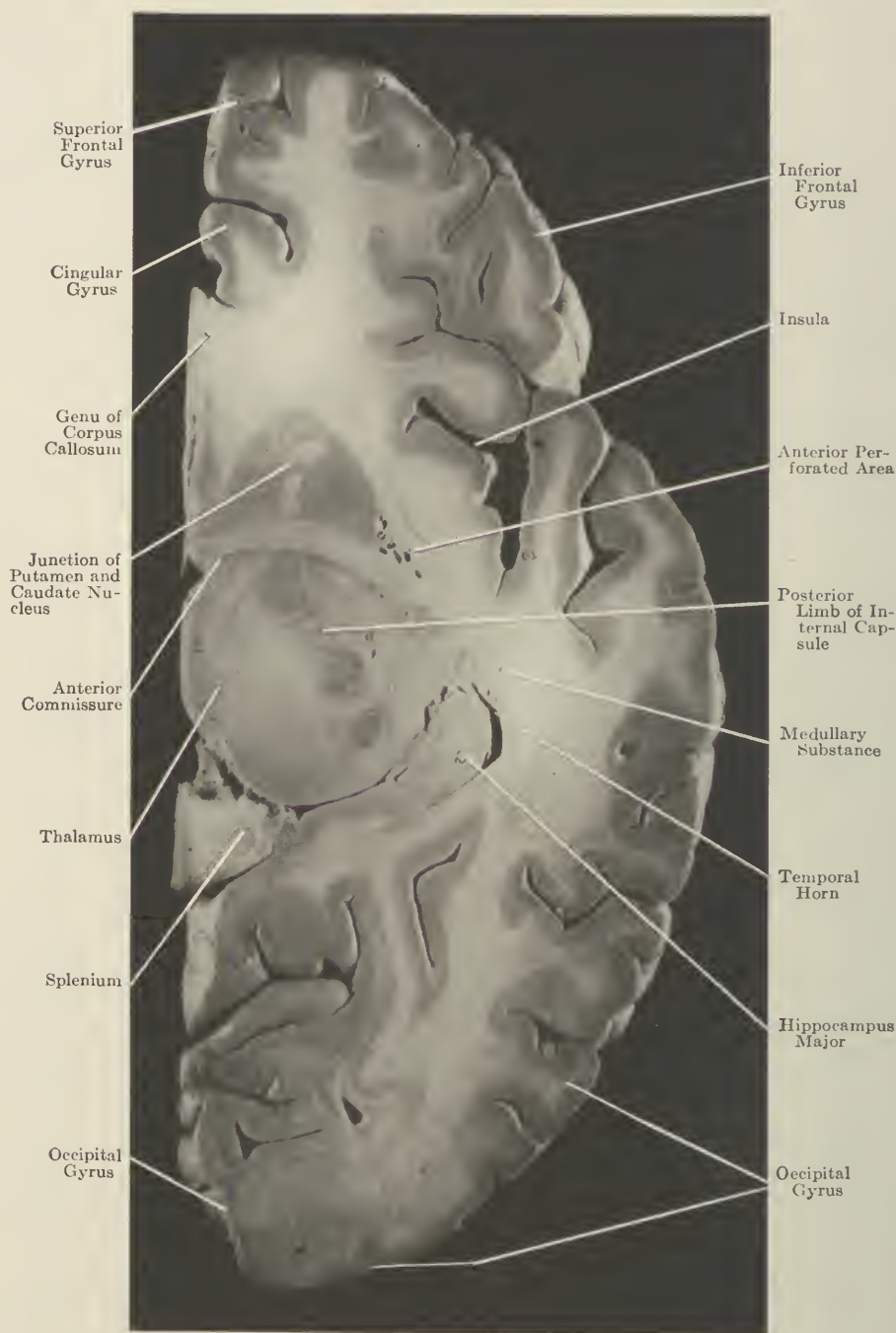


FIG. 573.—Horizontal section of hemisphere through the subthalamic portion of the internal capsule and the anterior commissure.

fibers still interpose themselves between these two portions of the neostriatum. Dorso-lateral to the putamen in the angle formed by it and the fibers of the anterior commissure are many small blood vessels which enter the brain at the anterior perforated space. These are ganglionic branches derived from the circle of Willis and serve to supply the basal ganglia. They are known as the *lenticulo-striate* and *lenticulo-thalamic vessels*. Immediately caudal to the anterior commissure is the remnant of the globus pallidus from which a small bundle of fibers may be seen sweeping in an arch around the cephalic extremity of the anterior limb of the internal capsule into the subthalamus. This bundle of fibers is the *ansa lenticularis*. It connects the globus pallidus with the red nucleus and other portions of the subthalamus. The subthalamus at this level presents the *zona incerta of Forel*.

The anterior limb of the internal capsule has practically disappeared. The head of the caudate nucleus is now in apposition with the putamen, separated from it by the interposition of some scattered bundles representing the anterior peduncle of the thalamus. The posterior limb of the internal capsule, now a massive bundle of fibers about to pass into the basis mesencephali, is situated between the subthalamus and the much reduced globus pallidus of the lenticular nucleus. Mesial to the internal capsule is the cephalic extremity of the red nucleus which projects forward for some distance in the subthalamus. It is impossible to distinguish any line of demarcation between the external and extreme capsules.

Passing transversely from the mesial aspect of the cortex, the fibers of the anterior commissure form a prominent bundle which separates the head of the caudate nucleus and putamen from the internal capsule. The fibers of the anterior commissure extend laterally into the medullary substance of the temporal lobe. The lateral ventricle at this level is represented by the temporal cornu, a small, slit-like space lateral to the *hippocampus major*. The ventral extremity of the chorioid plexus is present in this portion of the ventricle. (Fig. 573.)

Through the Cerebral Peduncle. In this section the cortex upon the lateral surface has a characteristic appearance. The transverse limb of the fissure of Sylvius separates the temporal from the frontal lobe. The line of Gennari is still visible in the occipital region. Upon the mesial surface the cortex covering the orbital convolutions is seen extending as far back as the brain-stem. Caudally the cortex extends from the occipital pole as far forward as the tip of the hippocampal fissure, which latter forms an invagination into the temporal cornu of the lateral ventricle producing the *pes hippocampi*. On the lateral surface, the cortex of the inferior frontal, inferior temporal and inferior occipital convolutions is present in its characteristic appearance.

The medullary substance is much reduced in amount and represents the ventral extremity of the mesial and lateral rays of the corona radiata. The basal ganglia and thalamus have disappeared. Occupying a ventromesial position is the portion of the brain-stem marking the transition



FIG. 574.—Horizontal section of hemisphere through the cerebral peduncle.

from interbrain to midbrain. In a lateral position is the collected mass of projection fibers constituting the cerebral peduncle and represented in the preceding section by the posterior limb of the internal capsule. These projection fibers contain the fronto-ponto-cerebellar, the cortico-nuclear, the pyramidal, and the parieto-temporo-occipito-ponto-cerebellar systems.

Mesial to the fibers of the cerebellar peduncle is the red nucleus now much increased in all of its diameters. The red nucleus is in contact with the central gray matter of the midbrain which in turn is invested along the free margin of the superior colliculus by the tectum mesencephali.

The lateral ventricle is represented by the temporal extremity of the temporal cornu now somewhat more extensive in size than in the sections

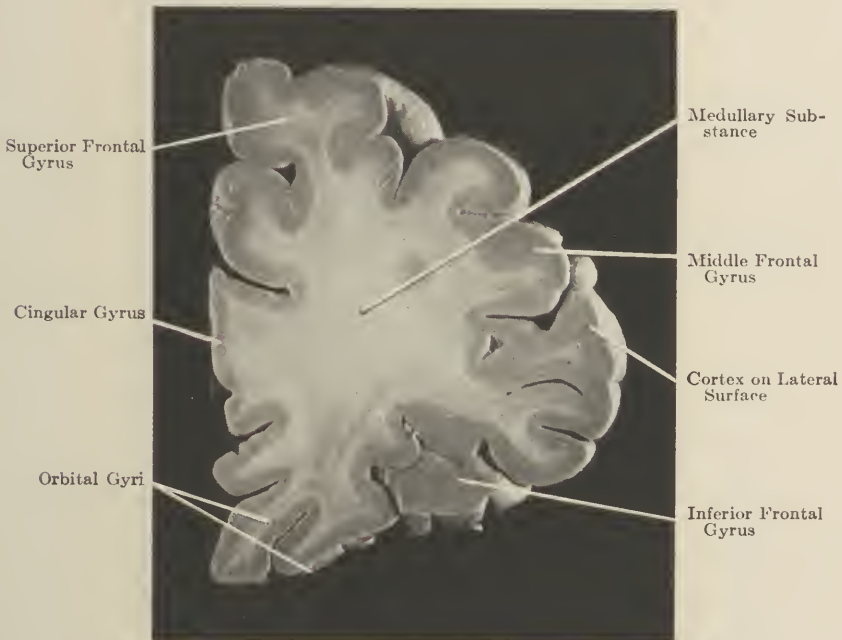


FIG. 575.—Coronal section of the frontal lobe near its frontal pole.

immediately above; while into it protrude two of the digitations which constitute the *pes hippocampi*. (Fig. 574.)

A SERIES OF SECTIONS MADE IN THE CORONAL PLANE

The Frontal Pole of the Frontal Lobe. Coronal sections at this level show the cortex of the frontal convolutions surrounding the central core of white matter which enters into the formation of the centrum ovale. (Fig. 575.)

Through the Cephalic Extremity of the Corpus Callosum. The cortex surrounds the medullary substance except for a small area indicating the position of the cephalic extremity of the genu of the corpus callosum. (Fig. 576.)

Through the Tip of the Frontal Horn of the Lateral Ventricle. The cortex at this level entirely surrounds the medullary substance with

the exception of a small area on the mesial surface indicating the position of the genu of the corpus callosum. Lateral to the fibers of the corpus callosum is the cephalic extremity of the frontal cornu of the lateral ventricle. The convolutions on the mesial surface are the superior frontal, cingular and orbital gyri; on the lateral surface, the middle and inferior frontal gyri. (Fig. 577.)

Through the Pole of the Temporal Lobe. At this level the cortex entirely surrounds the medullary substance with the exception of a small area on the mesial aspect indicating the genu of the corpus callosum lateral to which is the frontal cornu of the lateral ventricle.

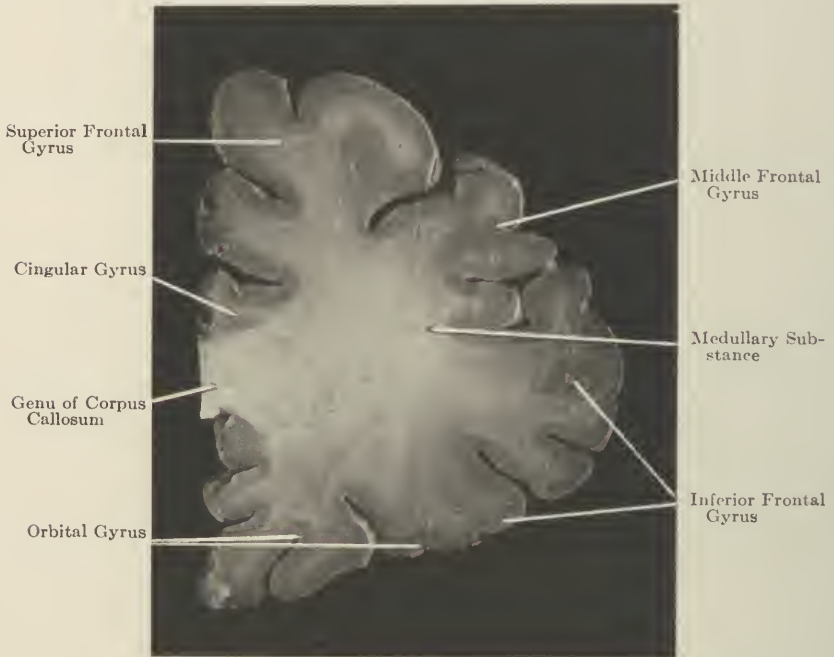


FIG. 576.—Coronal section of the frontal lobe through the cephalic extremity of the corpus callosum.

The convolutions on the mesial surface are the superior frontal, cingular and orbital gyri; on the lateral surface the middle and inferior frontal gyrus. Ventral to the inferior frontal gyri is the pole of the temporal lobe. (Fig. 578.)

Through the Head of the Caudate Nucleus. The cortex at this level invests the medullary substance with the exception of a small area on the mesial aspect indicating the position of the genu of the corpus callosum whose fibers here diverge in such a way that they form the roof and floor of the frontal cornu of the lateral ventricle. Projecting into the lateral wall of the ventricle is the head of the caudate nucleus. The convolutions upon the mesial surface are the superior frontal, cingular and orbital gyri; on the lateral surface, the middle and inferior frontal and temporal gyri. (Fig. 579.)

Through the Cephalic Extremity of the Internal Capsule. The medullary substance at this level is invested by the cortex with the exception of an area on the mesial aspect indicating the genu and rostrum of the corpus callosum lateral to which is the body of the lateral ventricle. The head of the caudate nucleus projects into the lateral wall of the ventricle, and contiguous with it laterally is a group of fibers representing the cephalic extremity of the internal capsule. Lateral to this mass of fibers is a collection of gray matter, the putamen, which is confluent ventrally with the head of the caudate nucleus. Slender bridges of gray matter pass through the internal capsule from the caudate nucleus to the putamen. The convolu-

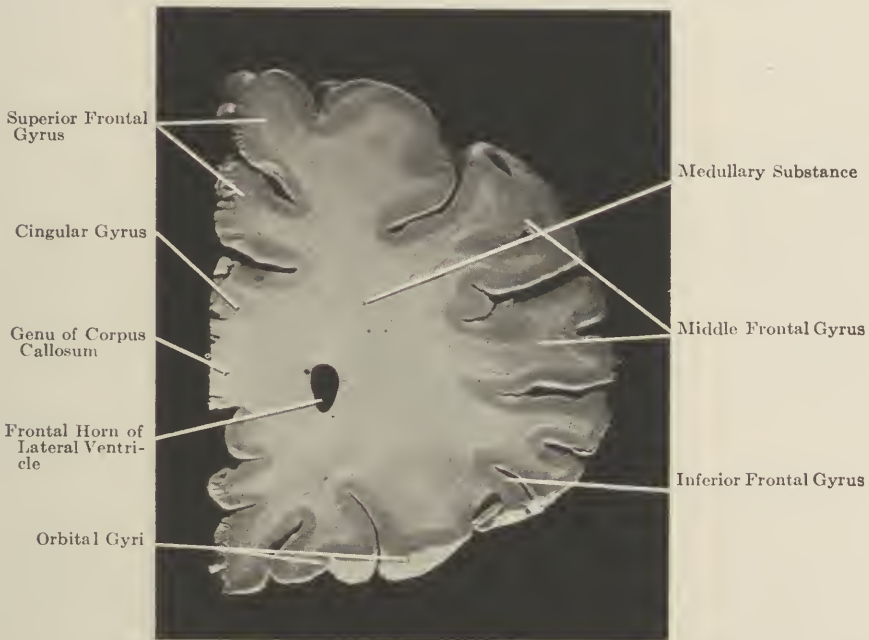


FIG. 577.—Coronal section of frontal lobe through tip of frontal horn of lateral ventricle.

tions on the mesial surface are the superior frontal, cingular and orbital gyri; on the lateral surface the middle and inferior frontal, the superior and middle temporal gyri. (Fig. 580.)

At the Point of Confluence of the Medullary Substance of the Temporal and Frontal Lobes. The medullary substance is almost completely invested by cortex with the exception of a small area indicated by the body of the corpus callosum. The body of the lateral ventricle is smaller than in the preceding section, the head of the caudate nucleus projecting into its lateral wall. Lateral to the caudate nucleus is the internal capsule somewhat increased in size. The caudate nucleus and putamen are still confluent ventrally. The medullary substance of the temporal and frontal lobes is now continuous. The frontal and temporal opercula are present and conceal the island of Reil. The convolutions on the mesial surface are the

superior frontal, cingular and uncinate gyri; on the lateral surface, the middle and inferior frontal, insular, middle and inferior temporal gyri. (Fig. 581.)

Through the Anterior Commissure. The medullary substance at this level is almost entirely invested by cortex, with the exception of a small surface on the mesial aspect of the hemisphere indicating the position of the body of the corpus callosum. The body of the lateral ventricle is still smaller than in the previous section and the body of the caudate nucleus projects into its lateral wall. The lateral boundary of the caudate nucleus is the anterior limb of the internal capsule which

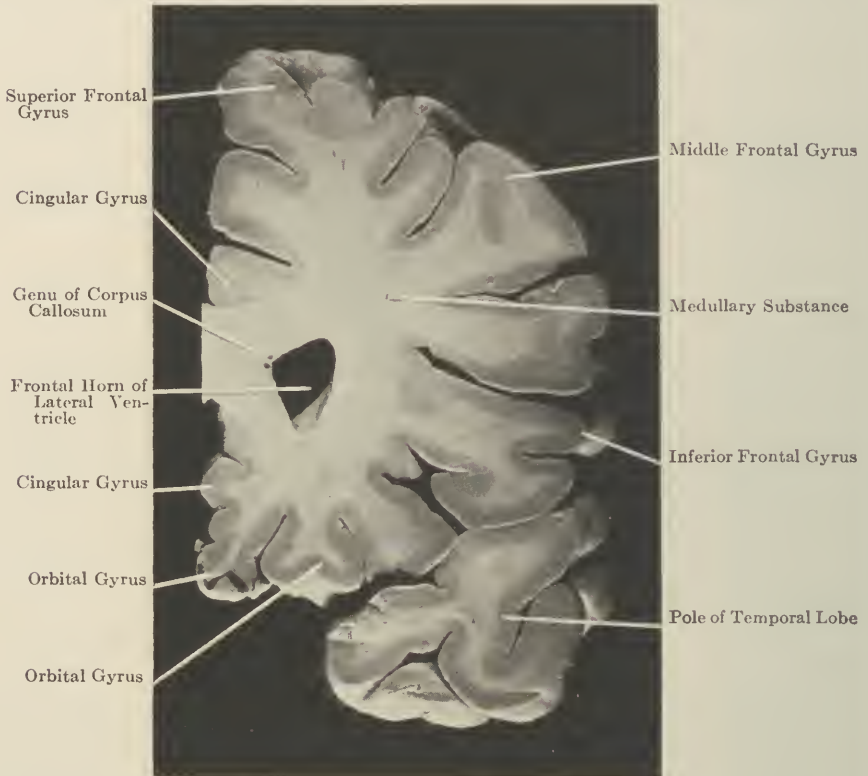


FIG. 578.—Coronal section of frontal lobe through pole of temporal lobe.

completely separates the caudate nucleus from the putamen. Ventral to the putamen and the caudate nucleus are the transverse fibers constituting the anterior commissure. The convolutions on the mesial surface are the superior frontal, cingular, gyrus subcallosus and gyrus uncinatus; on the lateral surface, the middle and inferior frontal, insular, middle and inferior temporal gyri. (Fig. 582.)

Through the Genu of the Internal Capsule. The medullary substance is here entirely surrounded by cortex with the exception of a small area indicating the body of the corpus callosum. The body

of the caudate nucleus projects into the lateral ventricle, lateral to which is the portion of the internal capsule forming the genu. Ventral to the internal capsule are some of the fibers of the anterior commissure, while laterally the two divisions of the lenticular nucleus are now discernible; namely, the globus pallidus and putamen. Lateral to the lenticular nucleus is the claustrum which is separated from the putamen by the capsula externa and from the island of Reil by the capsula extrema. The convolutions on the mesial surface are the superior frontal, cingular, and uncinate gyri. The detached portion situated ventrally indicates the pons Varolii. The convolu-

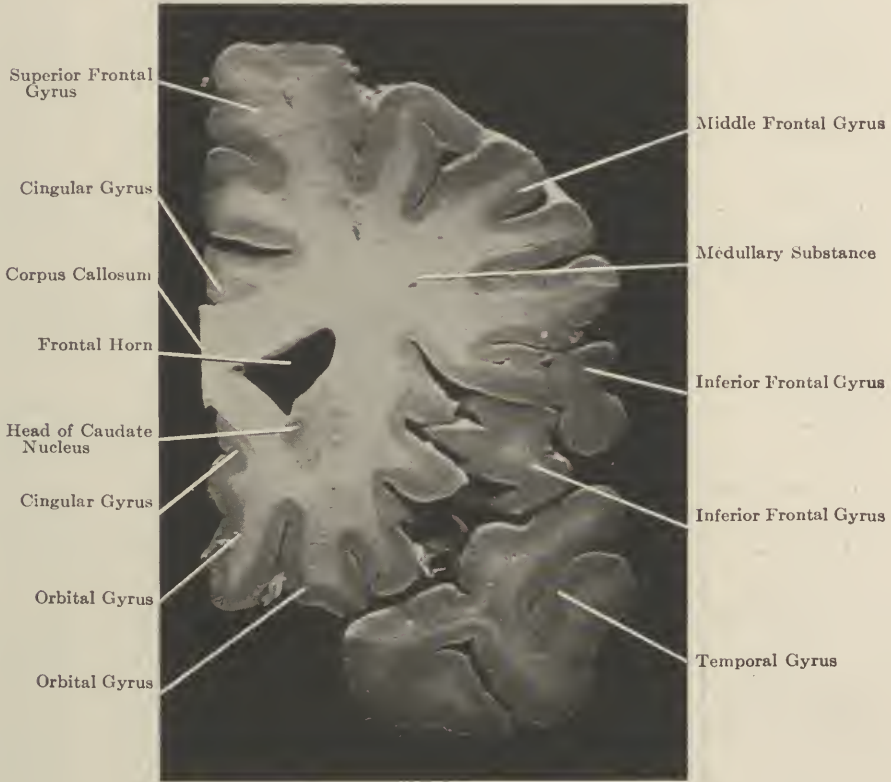


FIG. 579.—Coronal section of frontal lobe through the head of the caudate nucleus.

tions on the lateral surface are the middle, superior and inferior temporal and the insular gyri. Contained in the temporal lobe is the cephalic tip of the temporal cornu of the lateral ventricle. (Fig. 583.)

Through the Cephalic Extremity of the Cerebral Peduncle. The medullary substance, as in the previous sections, is almost completely surrounded by cortex with the exception of the mesial aspect, where the fibers of the corpus callosum still make their way inward above the body of the lateral ventricle. The body of the caudate nucleus is now much reduced in size, and ventral to it the cephalic extremity of the optic thalamus makes

its appearance. Lateral to these structures is the massive collection of fibers constituting the posterior limb of the internal capsule whose lateral boundary is the lenticular nucleus. The projection fibers of the internal capsule are seen making their way into the cephalic extremity of the cerebral peduncle, caudal to which is the pons Varolii. The claustrum, external and extreme capsules, occupy the same relative positions as in the preceding section. On the mesial surface the convolutions are the superior frontal and cingular gyri; on the lateral surface, the middle and inferior frontal and

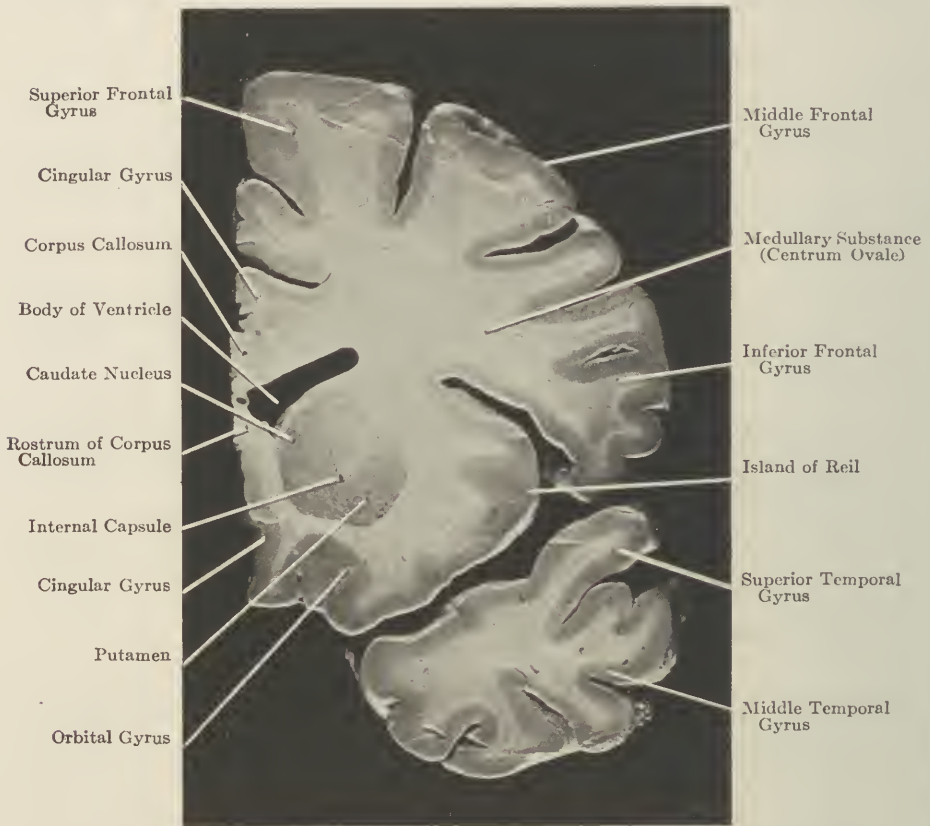


FIG. 580.—Coronal section of the frontal lobe. Cephalic extremity of the internal capsule.

insular gyri and the superior, middle and inferior temporal gyri. The temporal cornu of the temporal lobe is now enlarged, and projecting into it are two elevations constituting the hippocampus major. (Fig. 584.)

Through the Cephalic Extremity of the Cornu Ammonis. The medullary substance is still almost completely invested by cortex with the exception of the areas in which the body of the corpus callosum, the fornix and the optic thalamus are in relation with the hemisphere. The body of the lateral ventricle is reduced in size; its roof is formed by the fibers of the corpus callosum, its floor by the intraventricular portion of the optic

thalamus and the tail of the caudate nucleus. Lateral to the optic thalamus are the caudalmost fibers of the internal capsule, the lateral boundary of which is the lenticular nucleus. The island of Reil and the external and extreme capsules are much reduced in size. The convolutions on the mesial surface are the superior frontal and cingular gyri; on the lateral surface, the superior parietal, ascending parietal, superior, middle and inferior temporal gyri. On the mesial surface of the temporal lobe is seen the cephalic tip of the cornu Ammonis in relation with the temporal cornu of the lateral ventricle. (Fig. 585.)

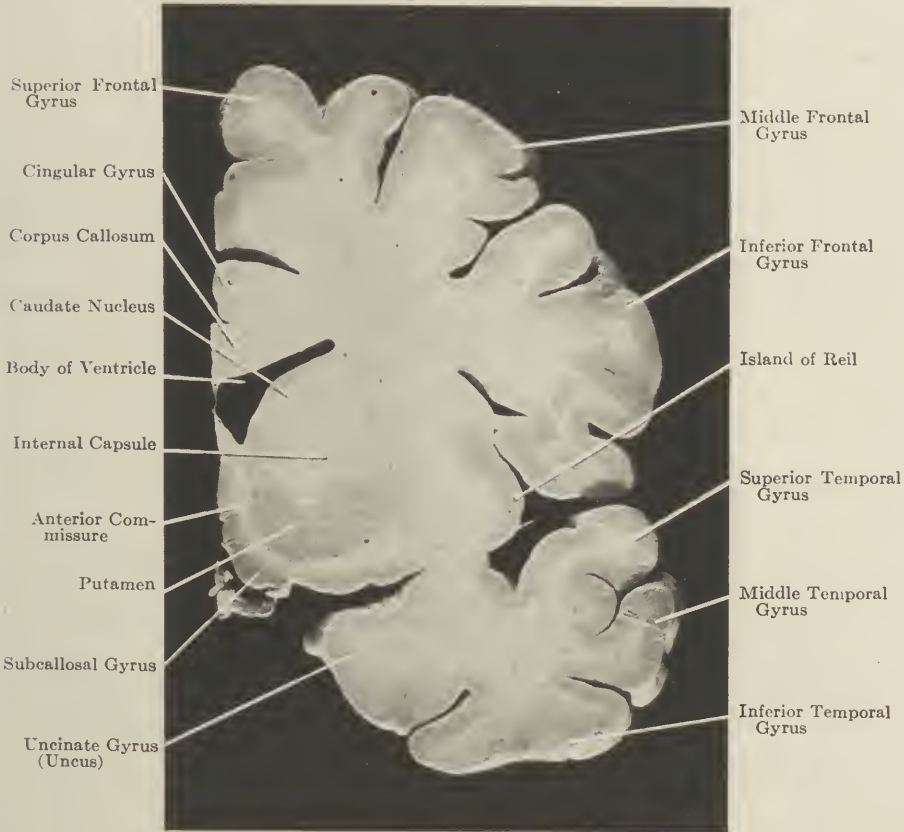


FIG. 581.—Coronal section at the point of confluence of the medullary substance of the temporal and frontal lobes.

Through the Retrolenticular Portion of the Internal Capsule. The medullary substance in this section is not so completely invested by cortex as in the immediately preceding sections. The body of the corpus callosum is somewhat reduced in size, as is also the body of the lateral ventricle, whose floor is now formed by the intraventricular surface of the optic thalamus and the tail of the caudate nucleus. The tela chorioidea is seen projecting into the lateral ventricle through the chorioid fissure. The main mass of the thalamus projects in toward the medullary substance of the

endbrain in which is the dense collection of fibers constituting the retrolenticular portion of the internal capsule. The lenticular nucleus has disappeared from the field. The convolutions seen upon the mesial surface are the superior frontal and cingular gyri; on the lateral surface the superior parietal, ascending parietal and the superior, middle and inferior temporal gyri. On the mesial aspect of the temporal lobe is the cornu Ammonis projecting into the temporal cornu of the lateral ventricle. (Fig. 586.)

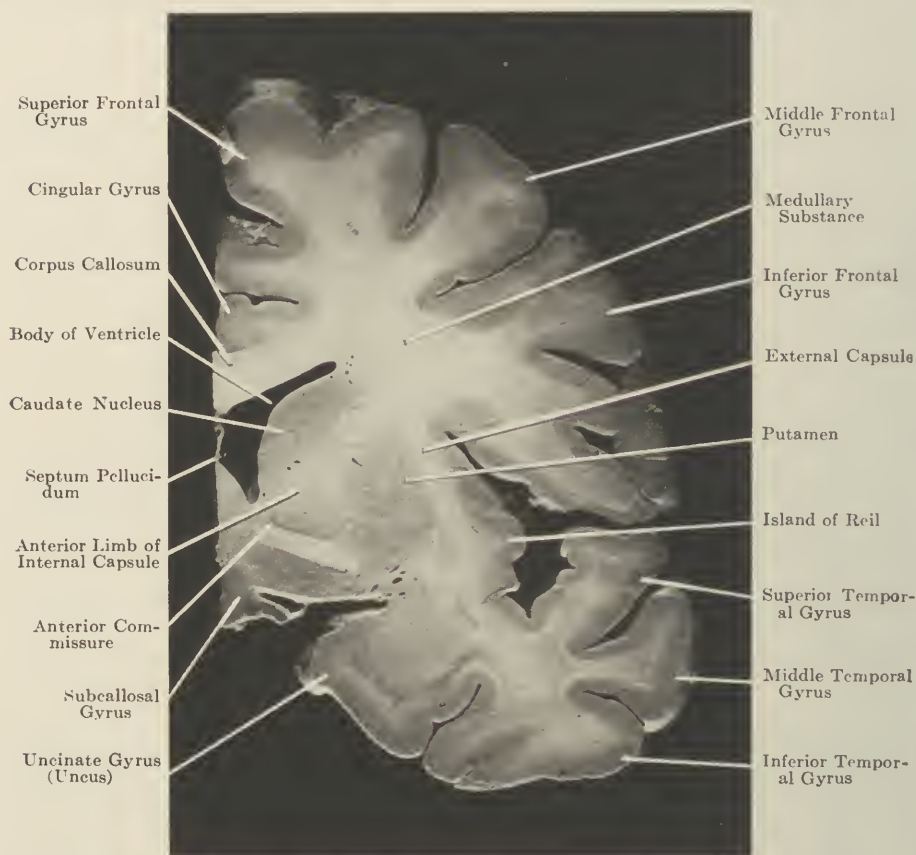


FIG. 582.—Coronal section through the anterior commissure.

Through the Atrium Ventriculi. The medullary substance at this level is entirely invested by the cortex with the exception of a large area on the mesial aspect indicating the position of the splenium of the corpus callosum, lateral to which is the atrium ventriculi, in which portion of the lateral ventricle the body, temporal cornu and occipital cornu become confluent. Lateral to the atrium ventriculi in the medullary substance is a dense bundle of fibers constituting the optic radiation. The tail of the caudate nucleus is seen descending along the lateral aspect of the atrium. The convolutions on the mesial surface are the gyrus precentralis, gyrus paracen-

tralis and gyrus cinguli, the gyrus fasciolaris, gyrus dentatus and gyrus hippocampi; on the lateral surface, the ascending parietal, superior, middle and inferior temporal gyri. (Fig. 587.)

Through the Occipital Horn of the Lateral Ventricle. The medullary substance at this level is entirely surrounded by cortex. Near its ventral aspect is the triangular cavity representing the occipital cornu of the lateral ventricle. Mesial to this is the massive bundle of fibers

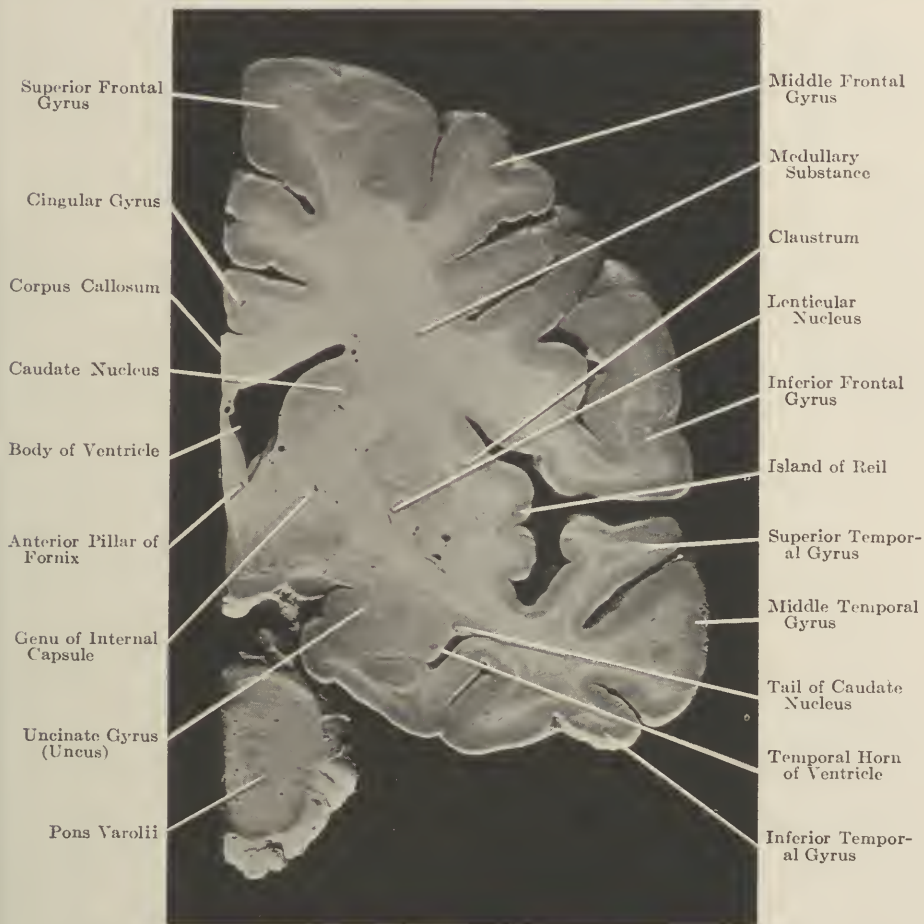


FIG. 583.—Coronal section through the genu of the internal capsule.

constituting the forceps major; and lateral to it is the fasciculus forming the optic radiation. The convolutions on the mesial surface are the postcentral, precuneal and lingual gyri; on the lateral surface the superior parietal, inferior parietal, inferior temporal and fusiform gyri. (Fig. 588.)

Through the Occipital Pole of the Hemisphere. The medullary substance at this level is entirely surrounded by cortex. All evidence of the occipital cornu of the lateral ventricle has disappeared. The convolutions

upon the mesial surface are the superior parietal, cuneal and lingual gyri; on the lateral surface, the inferior parietal, middle and inferior occipital gyri. (Fig. 589.)

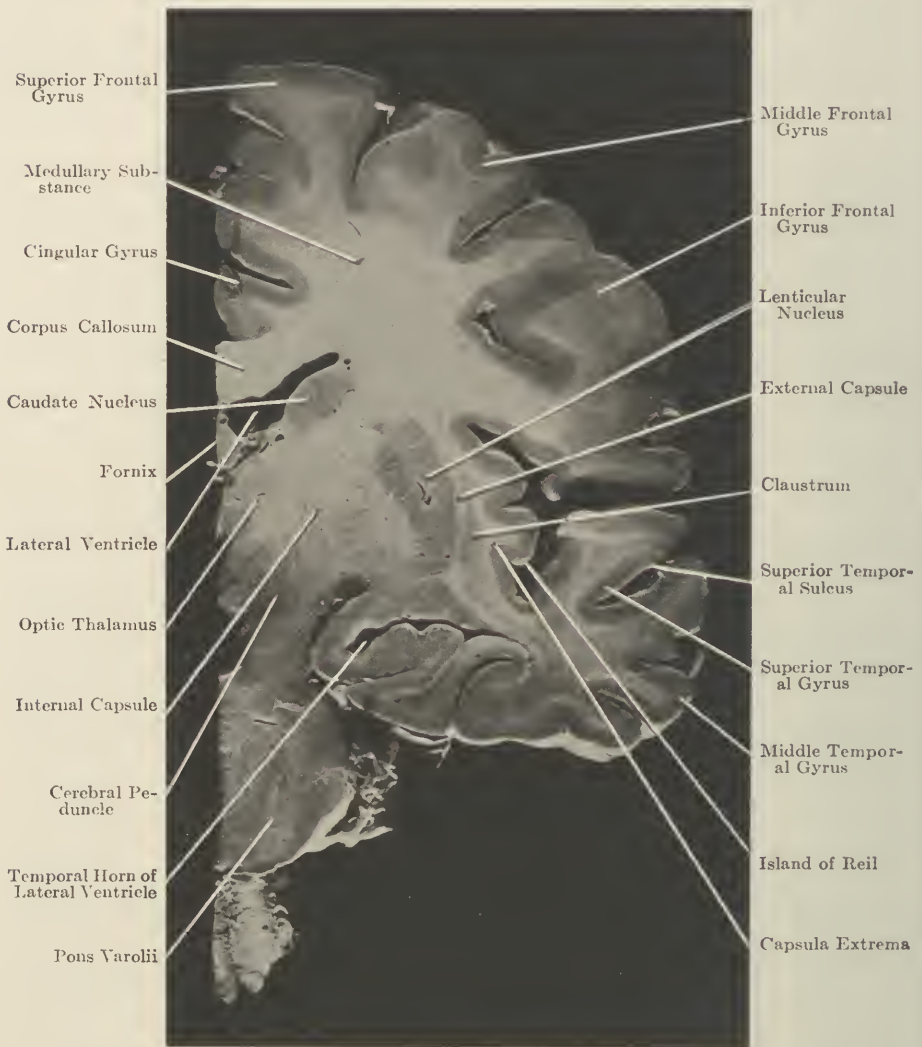


FIG. 584.—Coronal section through the cephalic extremity of the cerebral peduncle.

THE LATERAL VENTRICLES

Each of these hemispheres contains a cavity lined with ependyma and connected with the third ventricle by means of a small opening, the *foramen of Monro*; this cavity is the lateral ventricle. Each lateral ventricle is an irregular space situated beneath the most ventral fibers of the corpus callosum, surrounded by medullary substance upon its lateral and dorsal

aspects, and in close relation with the mesial surface of the hemisphere. The lateral ventricle represents the remains of the primitively large cavity which appears in the embryonic forebrain. As a result of the expansion of the cortex, the growth of the medullary substance and basal ganglia, and the moulding of the brain especially in the development of the temporal lobe, the original cavity not only becomes reduced in size, but presents certain modifications in form consequent upon its adaptation to the surfaces of the brain.

In man, the divisions of the lateral ventricle may be distinguished as: the *frontal horn*, situated in the frontal lobe; the *occipital horn*, situated in the occipital lobe; the *temporal horn*, occupying the temporal lobe, the *body* which is a caudal continuation of the frontal horn, and the *atrium ventriculi*.

The Frontal Horn. The frontal horn of the ventricle, situated in the frontal lobe, is about 2.5 cm. in length and 1.25 cm. in breadth. It extends from the orifice of the foramen of Monro as far forward as the caudal fibers of the genu of the corpus callosum. Its outer boundary is formed by the dorso-mesial surface of the head of the caudate nucleus. Its mesial boundary is formed in large part by the septum pellucidum, its roof by the fibers of the corpus callosum, its floor by the confluence of the head of the caudate nucleus and fibers of the rostrum of the corpus callosum. Its anterior extremity is limited by the fibers in the genu of the corpus callosum. It is continued caudally as the body of the lateral ventricle.

The Body (Pars Centralis). The body of the lateral ventricle, also called the *pars centralis*, is continuous cephalad with the frontal horn. The line of division between these two portions of the ventricle is an arbitrary one, but the foramen of Monro is usually assigned as the point of demarcation. The dorsal and cephalic portion of the body extends backward in a slightly arched manner for 3.75 cm. where it bends and passes into the *atrium ventriculi*, a portion of the ventricle which marks the confluence of the body, occipital and temporal horns. In coronal section of the brain the body of the lateral ventricle has a triangular outline. The apex of this triangle is directed outward toward the medullary substance; the base is directed inward. In consequence of its configuration, the body of the lateral ventricle for the most part lies above the dorsal surface of the thalamus. Its roof is formed by the fibers of the corpus callosum. The apex of the triangle is in relation with the fasciculus occipito-frontalis. Its floor is formed by the body of the caudate nucleus and the intraventricular surface of the thalamus. This area of the thalamus and the caudate nucleus is covered with a layer of ciliated ependymal cells. The edge of the body of the fornix constitutes the most mesial structure, forming the floor of the body of the ventricle. This structure lies immediately beneath the corpus callosum. It is a tract of longitudinal fibers, broadening behind as it passes beneath the splenium to form the fimbria, and bifurcating in front to form two cylindrical bundles, each of which passes over and in front of the foramen of Monro to form the anterior pillars of the fornix (*columnæ fornixis anteriores*). Projecting beneath the lateral edge of the fornix in relation with

the floor of the body of the lateral ventricle is a layer of pia mater, having the arrangement of a chorioid plexus. This is the tela chorioidea or chorioid glands of the lateral ventricle. It extends from the foramen of Monro caudally through the atrium and temporal horn of the lateral ventricle. There is no chorioid plexus found in the frontal or occipital horns of the ventricle.

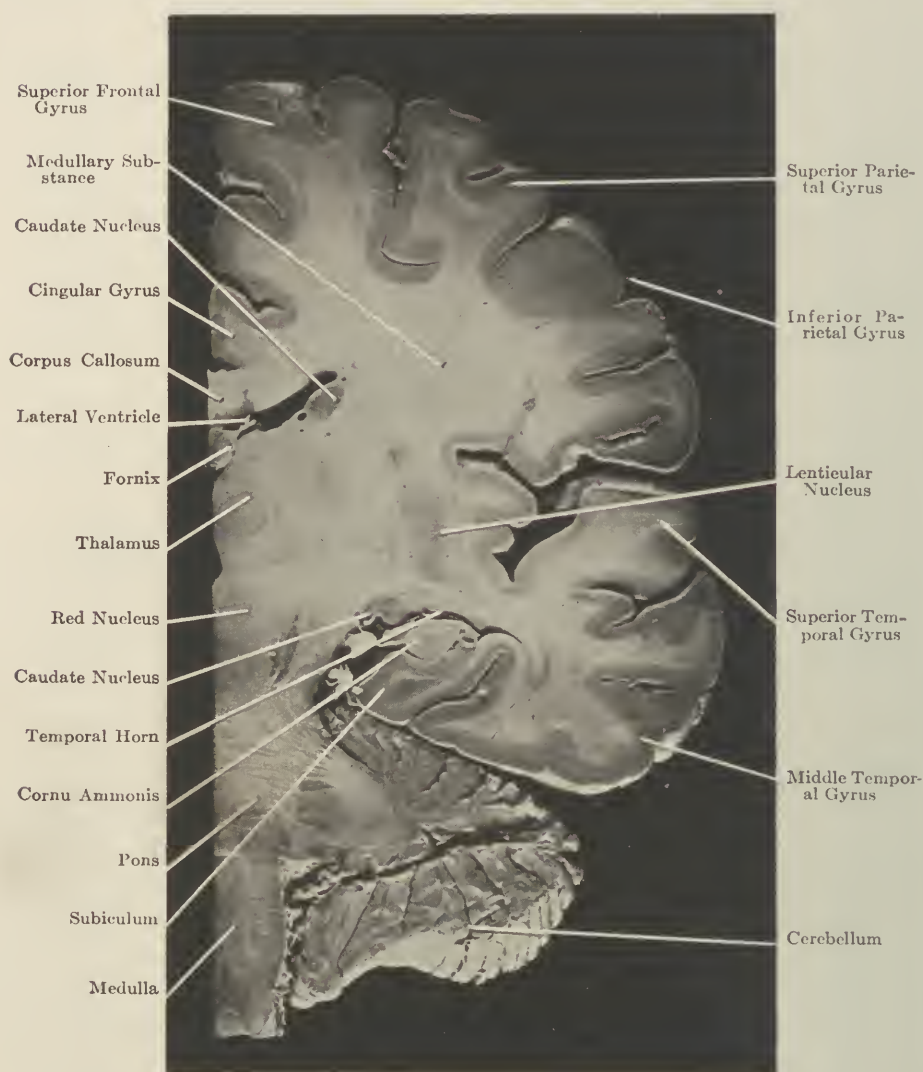


FIG. 585.—Coronal section through the cephalic extremity of the cornu Ammonis.

Lateral to the chorioid plexus is the *thalamo-caudate sulcus*, which separates the dorsal surface of the caudate nucleus from the dorsal surface of the thalamus. A narrow band of white fibers, *tenia semicircularis*, runs in this groove and gradually increases in size as it proceeds forward. In

addition to this band of white fibers there is a vein, the *vena terminalis* or *caudate vein*, which extends forward superficially to the tenia, and turns inward to pass through the foramen of Monro, where it joins the vein of the septum pellucidum to form the *vein of Galen*.

Beneath the endyma, but in a position superficial to the terminal vein,

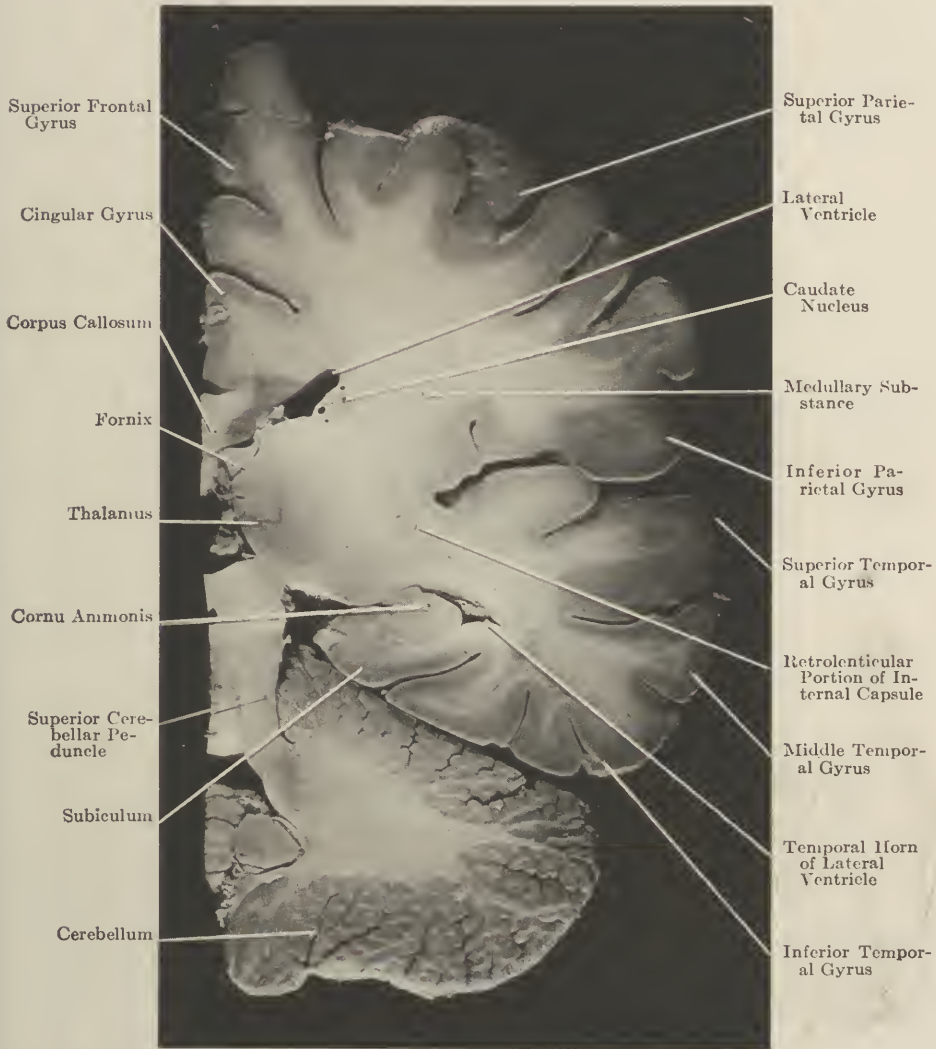


FIG. 586.—Coronal section through the retro-lesional portion of the internal capsule.

is a small grayish band containing longitudinal nerve fibers which follows the course of the thalamo-caudate sulcus throughout its entire extent. This is the *lamina cornea*, the attenuated wall of the endbrain vesicle, which during development has become adherent to the diencephalon in this position.

The body of the caudate nucleus, which gradually becomes narrower on proceeding caudally from the foramen of Monro, upon reaching the atrium ventriculi turns downward into this part of the ventricle and sweeps forward into the roof of the temporal cornu. On the mesial aspect of the upper part of the body of the ventricle there is a narrow groove between the corpus



FIG. 587.—Coronal section through the atrium ventriculi.

callosum and the fornix. This is bounded mesially by the posterior extremity of the septum pellucidum and finally by the direct union between the corpus callosum and the body of the fornix.

Upon reaching the caudal extremity of the thalamus the body of the ventricle bends in a sweeping arch downward and somewhat outward, and in this position becomes continuous ventrally with the temporal horn and caudally with the occipital horn. In making this arched curve from its former

horizontal plane into a nearly vertical one, the floor becomes the cephalic wall of the atrium. On the mesial and cephalic wall of this descending portion of the body of the ventricle appears the beginning of the hippocampal eminence. In a still more ventral position on the mesial wall, between the occipital and temporal horns, is a triangular area, the *trigonum ventriculi*,

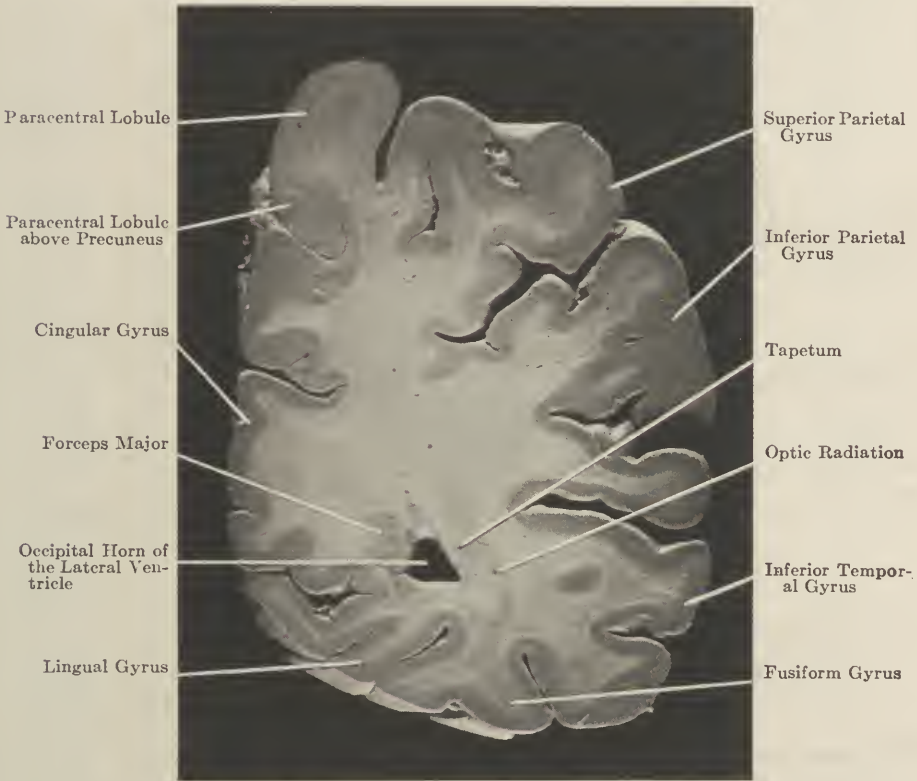


FIG. 588.—Coronal section through the occipital horn of the lateral ventricle.

the greater portion of which is occupied by a smooth levation, the *eminentia collateralis*. This ventricular relief corresponds to the collateral fissure.

The Occipital Horn. The occipital horn is the caudal continuation of the body, and curves around the lower extremity of the parieto-occipital fissure. It is surrounded by the fibers of the corpus callosum, which pass from the temporal and occipital lobes. On the dorsal portion of its mesial wall is the bundle of fibers forming the forceps major, which sweeps from the splenium of the corpus callosum into the occipital lobe. This bundle causes a projection into the cavity of the occipital horn, the *bulbus cornu posterioris*. Situated below the bulb is another eminence extending from the base of the occipital cornu. This eminence on the mesial wall corresponds to the anterior portion of the calcarine fissure and is known as the *calcar avis*. This elevation does not appear in the human brain alone, but is found in

several of the anthropoids. The occipital horn in man varies considerably in size and the calcar avis is likewise variable in its prominence.

The roof and part of the mesial wall of the occipital horn are formed by the medullary substance of the lobulus lingualis and the forceps major. The lateral wall and floor are formed by the tapetum, lateral to which lie the optic radiation of Gratiolet and the fasciculus longitudinalis inferior.

The Temporal Horn. The temporal horn of the ventricle is directed ventro-cephalically. It extends from the ventral portion of the body of the ventricle, curving somewhat inward, to end at a point about 2.75 cm. from

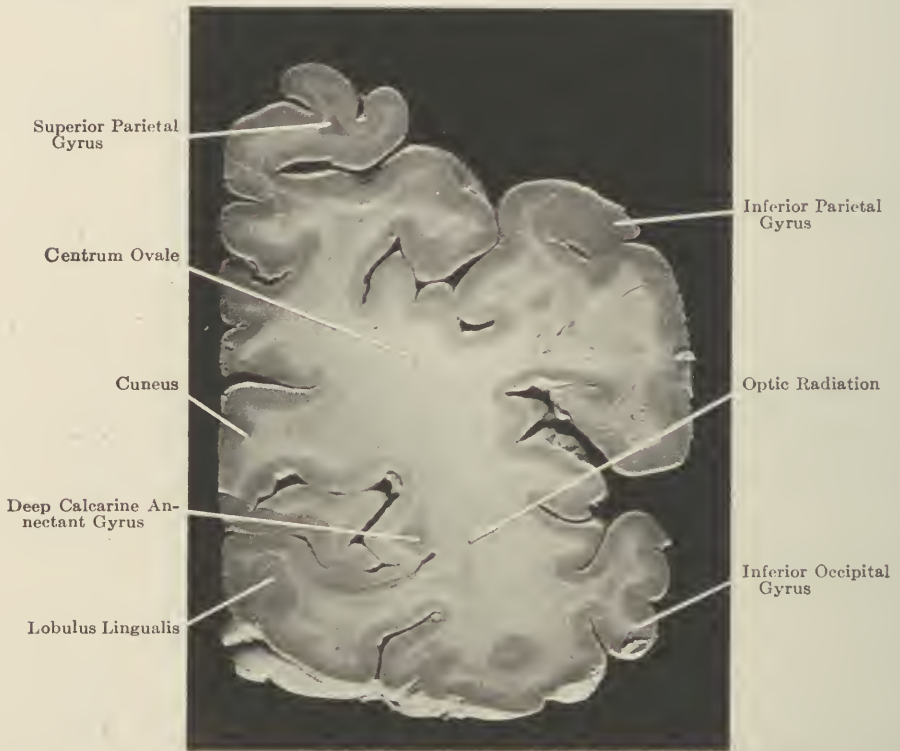


FIG. 589.—Coronal section of the hemisphere near the occipital pole.

the apex of the temporal lobe. Its roof and lateral wall are formed by fibers of the corpus callosum arching from side to side into the temporal lobe and forming the tapetum. The tail of the caudate nucleus and the tenia semicircularis are continued forward to form the remainder of the roof of the descending horn. The caudate nucleus and tenia semicircularis, which constituted elements in the floor of the body of the ventricle, have reversed their position in consequence of the arch about the optic thalamus and lie in the roof of the temporal horn.

In the floor of the temporal horn is a large eminence which extends almost to the roof. This is the *hippocampus*. It becomes larger as it proceeds

toward the temporal pole, and has a somewhat digitated appearance resembling an animal's paw, for which reason it is called the *pes hippocampi*. The hippocampus corresponds in position to the hippocampal fissure. The deep invagination occasioned by the in-rolling of the hippocampus carries the hippocampal fissure well in toward the ventricle. Mesial to the hippocampus is a broad flat band of fibers, the fimbria, which is a prolongation from the body of the fornix. Over the fimbria at the angle which the floor forms with the roof, the chorioid plexus projects into the ventricle and forms the mesial boundary of that cavity. The dorsal extremity of the chorioid plexus is attached to a small ridge of gray matter, the *crest of the tenia semicircularis*; ventrally it has an attachment to the fimbria along a slight elevated ridge, the *ependymal crest of the fimbria*. If the pia mater is drawn out and separated from the two attachments just mentioned, the temporal horn is opened and may be entered from the mesial surface. This opening is a continuation of the great transverse fissure which follows the course of the tela chorioidea between the ventral surface of the fornix and the dorsal surface of the optic thalamus. The fissure in reality represents the line of invagination of the pia mater which forms the chorioid glands of the lateral ventricle. During this process of invagination the pia and its glomerular processes receive an investment from the ventricular ependyma which is pushed inward before the pial process. With the chorioid plexus still attached, a deep sulcus marks the position of this transverse fissure. This is the *chorioid fissure*, one of the earliest to appear during embryonic development.

The Embryological and Developmental Significance of the Ventricular System. It is particularly advantageous at this point to consider the ventricular system of the central nervous system as a whole. The lateral ventricles represent the residuum of the formerly spacious cavity in the embryonic endbrain. Each lateral ventricle (*ventriculus telencephali*) is connected by means of a small aperture, the foramen of Monro, with the dorso-cephalic portion of the third ventricle (*ventriculus diencephali*). The third ventricle presents two main divisions and a number of recesses. A cephalic division lies in front of the commissura mollis, and a caudal division behind this commissure. The cephalic extremity of the third ventricle properly belongs to the endbrain and constitutes the *aula*. This portion of the third ventricle is determined by a line drawn from the dorsal boundary of the foramen of Monro to the dorsal portion of the chiasmatic eminence. Its cephalic boundary is the *lamina terminalis*. Dorsally, it is bounded by the arching of the anterior pillars of the fornix; ventrally by the optic chiasm. Caudally it is continuous with the diencephalic division of the third ventricle. One recess in the aula is found immediately ventral to the foramen of Monro and dorsal to the anterior commissure. This is the *supra-commissural recess*. Another recess appears in a cephalic position in relation to the chiasm. This is the *preoptic recess* which is continued laterally, especially in the infant and young adult, for a short distance over the optic chiasm, along the optic nerve, to form the *supra-optic canal*. The floor of the third ventricle presents a small

accessory recess which extends toward the stalk of the infundibular process. This is the *postchiasmatic recess* or *recessus bulbi infundibuli*.

The roof of the third ventricle presents two parallel rows of chorioidal glands extending in a longitudinal direction from the foramen of Monro toward the iter Sylvii. At the junction of the roof with the caudal boundary of the third ventricle two accessory recesses occur; one, the *suprapineal recess*, extending above the pineal gland, and the other, the *pineal recess*, extending into the peduncle of this organ.

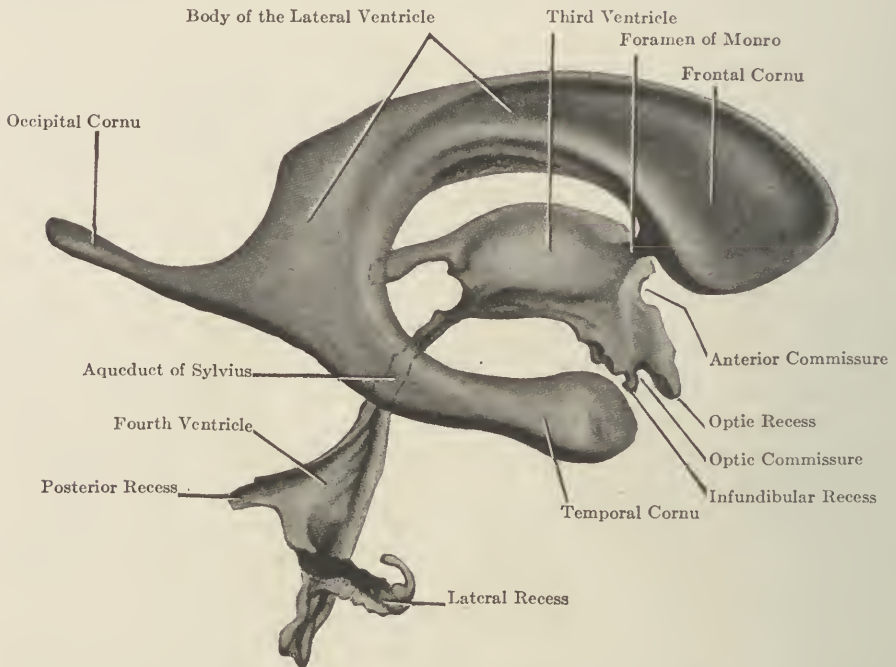


FIG. 590.—Cast of the ventricles of the brain viewed from the right-side. (*Retzius*.)

The third ventricle, which is the remnant of the original spacious cavity in the diencephalon, communicates with the fourth ventricle by means of the *aqueduct of Sylvius* (*iter e tertio ad quartum ventriculum*). In its primitive state the aqueduct of Sylvius is one of the largest of the brain vesicles, but it has become reduced to a small tubular canal by the rapid growth in the tegmentum and tectum of the midbrain. In the animals in which the optic lobes develop to large dimensions the ventricle of the midbrain presents a central canal communicating with two large accessory recesses, one in either optic lobe. The recession in prominence of the tectum mesencephali with the appearance of the quadrigeminal bodies causes the two lateral accessory recesses of the Sylvian aqueduct to disappear, although their presence may be observed in the early stages of development in mammals.

The fourth ventricle presents another expansion in the encephalic cavity. In contrast to the third ventricle it lies chiefly in the frontal plane, whereas the principal plane of the third ventricle is sagittal. From this relation it

results that the floor of the fourth ventricle corresponds to the dorsal aspect of the medulla oblongata. The features in the ventricular floor have already been discussed. (See page 365.) The floor of the ventricle itself is lozenge-shaped and consists of two isosceles triangles in contact at their bases. The more cephalic of the two triangles is bounded laterally by the superior and middle cerebellar peduncles. The apex of this triangle is continuous through the isthmus with the aqueduct of Sylvius. The caudal triangle is bounded laterally by the clava and cuneus. These lateral walls,

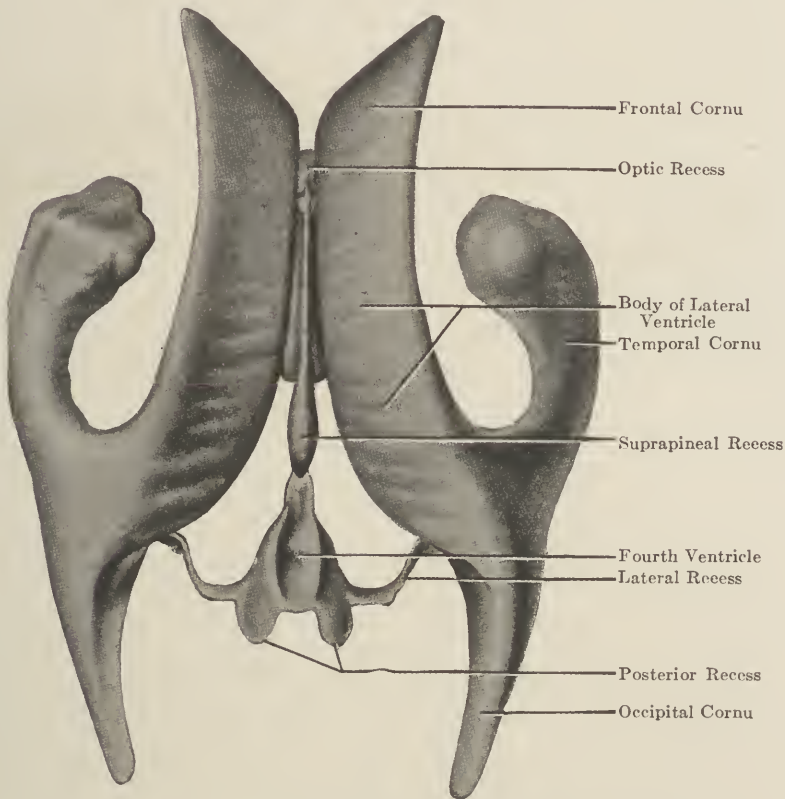


FIG. 591.—Cast of the ventricle of the brain viewed from above. (*Retzius*.)

however, are not coextensive with the entire length of the floor in the caudal triangle. Their elevation gradually decreases on approaching the cephalic triangle, in consequence of which there is a small space in the lateral boundary of the caudal triangle upon either side which has no limiting elevation in the form of a lateral wall. This hiatus in the boundary of the ventricle marks the position from which the lateral recess is evaginated, and also indicates the area in which the acoustic fibers pass over the lateral boundary of the ventricle in order to traverse its floor.

The roof of the fourth ventricle is peaked in a manner similar to the roof of a tent, the cephalic aspect being formed by the *superior medullary*

velum, while the inferior aspect consists of the *inferior medullary velum*. This roof-plate slopes gradually up to the junction of the inferior and the superior vermis cerebelli.

The fourth ventricle presents several recesses. One is situated at the junction of the superior and posterior medullary vela and constitutes the *fastigial recess*. Another much larger accessory recess results from the evagination of the roof-plate at the junction of the cephalic and caudal triangles of the ventricle. This is the *lateral recess*. It extends forward and downward much like a glove finger along the lateral aspects of the medulla and occupies a position in relation with the seventh, eighth, ninth and tenth nerves. It is not merely an evagination of the roof-plate, for it carries with it a process of the inferior tela chorioidea or chorioidal glands of the fourth ventricle, which gives it a glomerular appearance as it presents itself on the lateral aspect of the medulla in relation with the nerves just mentioned. The lateral recess is not closed, but by two foramina known as the *lateral foramina of Retzius and Key*, and another opening called the *foramen of Luschka*, a means for escape of the spinal fluid into the subarachnoid space is provided.

GLOSSARY

ACINUS. The smallest lobule of a gland.

ACROGNOSIS. Limb knowledge; sensory recognition of a limb and its several parts.

ADIADOCHOKINESIS. The inability voluntarily to produce rapid succession movements.

ADITUS, AUDITORY. The approach for auditory stimuli to the acoustic receptors.

AFFERENT. Conducting toward the central nervous system and toward the higher centers within the central nervous system.

AGENESIS. Failure of development in some part or parts of the body.

AGRAMMATISM. Ungrammatical use of language in individuals formerly capable of proper diction.

AGRAPHIA. A form of apraxia in which the individual is unable to write.

ALEXIA. Inability to read written or printed characters in an individual formerly able to read.

ALVEUS. The sub-ependymal medullary substance connected with the cornu Ammonis.

AMEBOID. Having characteristics similar to the ameba, a minute protozoan animal.

AMNION. The inner sac surrounding the mammalian embryo and containing the amniotic fluid.

AMPHIOXUS. A small fish-like animal about 2 inches long, having a body tapering at both ends.

AMPULLA. A saccular dilatation or vesicle connected with the semicircular canals of the ear.

AMUSIA. Inability to recognize musical sounds in an individual previously able to understand music.

AMYOTROPHIA. A state of the muscles in which the muscular tissue is deprived of its proper myotrophic control by the nervous system.

ANASTOMOSIS. An intercommunication of vascular channels.

ANGIOSPASM. A spasm in the circular coats of blood vessels more or less completely obstructing the flow of blood.

ANOREXIA. Loss of appetite.

ANSA LENTICULARIS. The fasciculus of fibers connecting the lenticular nucleus with the subthalamic region and red nucleus.

APHASIA. A form of apraxia in which an individual formerly able to speak is deprived of the ability to express himself in spoken language.

APNEA. A cessation of respiration.

APOPLEXY. A sudden loss or diminution of volitional control of the muscles, usually attended by unconsciousness and due to lesions of the brain.

APRAXIA. The loss of the power to perform skilled movements in any part of the body in the absence of actual paralysis in this part, due to lesions of the brain.

AQUEDUCT OF SYLVII. A small tubular canal connecting the third and fourth ventricles of the brain.

ARACHNOID. A membranous covering of the central nervous system situated between the dura mater and the pia mater.

ARBORIZATION. The branching of the neurofibrils at the termination of the neurone.

- ARBOR VITÆ.** The medullary substance as it appears on sagittal section of the human cerebellum.
- ARC, NEURAL.** A combination of four or more neurones constituting a complete circuit between certain receptors and effectors of the body. Such arcs serve for the most complex combination of nerve impulses resulting in *neural reactions*.
- ARC, REFLEX.** The direct connection by means of two or more neurones between receptors and effectors of the body through the spinal cord or brain stem. The reaction determined by such an arc is a *reflex act*.
- ARCH, EPIPHYSEAL.** The embryonic fundament in the roof of the third ventricle from which the pineal and parapineal organs take origin.
- ARCH, PARAPHYSEAL.** The embryonic fundament in the roof of the third ventricle from which the paraphysis takes origin in some of the lower vertebrates.
- ARCH, POSTVELAR.** The embryonic fundament in the roof of the third ventricle from which the superior tela chorioidea takes origin.
- ARCHIPALLIUM.** That part of the cerebral cortex developed from the telencephalon which forms the olfactory portion of the brain.
- AREA OF BROCA.** The caudal portion of the inferior frontal convolution on the left side in right-handed individuals. It is supposed to be the motor speech center.
- AREA PAROLFATORIA.** A portion of the primordial rhinencephalon connected with the sense of smell.
- AREA SPONGIOSA.** The peripheral portion of the dorsal gray column of the spinal cord in contact with the substantia gelatinosa.
- ARKYochrome.** A nerve cell in which the Nissl bodies are arranged in a reticulum.
- ASTASIA.** The inability to stand up without falling in the absence of actual paralysis, usually a hysterical symptom.
- ASTHENIA.** A marked loss of strength or muscular power—weakness.
- ASTROCYTES.** Neuroglial cells, radiate in form.
- ATAXIA.** Loss of the power to coordinate properly; a symptom due to a disturbance of synergy.
- ATAXIA, LOCOMOTOR.** (Also known as *TABES DORSALIS*). A disease of the nervous system characterized by marked disturbance in locomotion and due to a syphilitic process especially affecting the dorsal root fibers.
- ATHETOSIS.** A form of hyperkinesis or abnormal motor disturbance commonly associated with disease of the corpus striatum.
- ATONIA.** A decrease or loss of the proper muscle tone.
- ATRIUM OF THE OTOCYST.** The sacculle connected with the semicircular canals, ductus endolymphaticus and cochlea.
- ATRIUM OF THE VENTRICLE.** The portion of the lateral ventricle connected with the body, temporal and occipital cornu.
- ATROPHY.** A wasting of tissue due to improper nutrition.
- AULA.** The unpaired portion of the telencephalon forming the cephalic portion of the third ventricle.
- AXIS, CEREBROSPINAL.** The portion of the central nervous system contained within the vertebral canal and skull.
- AXIS CYLINDER PROCESS.** The process of the neurone which conducts the impulses away from the cell body.
- AXONE.** The portion of the neurone consisting of the neurofibrils, which serves to conduct the nerve impulses away from the body of the cell.

- BAND OF BROCA** (also known as **DIAGONAL BAND OF BROCA**). A portion of the primordial rhinencephalon in close relation with the anterior perforated space.
- BAROGNOSIS**. The cognitive process by which differences in weight are recognized (weight-knowledge).
- BLASTODERM**. One of the early stages in the development of the embryo.
- BODY, GENICULATE, LATERAL**. A relay center in the visual pathway connected with the optic thalamus.
- BODY, GENICULATE, MESIAL**. A relay center in the auditory pathway connected with the optic thalamus.
- BODY, MAMMILLARY**. One of a pair of eminences in the pars hypothalamica of the interbrain.
- BODY, NISSL** (also known as **TIGROID BODY**). The chromophilic substance found in the cytoplasm of the nerve cells.
- BODY, PACCHIONIAN**. Specialized processes of the arachnoid situated in relation with the superior longitudinal sinus of the dura mater.
- BODY, RESTIFORM**. The inferior cerebellar peduncle serving to connect the medulla oblongata and spinal cord with the cerebellum. An afferent pathway to the vermis cerebelli.
- BODY, TIGROID**. See *Body, Nissl*.
- BODY, TRAPEZOID**. Transverse decussating fibers in the ventral portion of the medulla and pons forming secondary tracts in the auditory pathway.
- BRACHIUM CONJUNCTIVUM**. The superior cerebellar peduncle.
- BRACHIUM CORPORIS QUADRIGEMINUM INFERIUS**. A link in the auditory pathway connecting the inferior corpora quadrigemina with the mesial geniculate body.
- BRACHIUM PONTIS**. The middle cerebellar peduncle.
- BRADYKINETIC ANALYSIS** (*Brady*—slow, *Kinetic*—pertaining to motion). A means of analyzing motor activity by ultra rapid motion pictures.
- BRANCHIOMERE**. One of the gill segments.
- BULB OR BULBUS MEDULLARIS**. The medulla oblongata.
- BULBUS INFUNDIBULI**. The portion of the pars hypothalamica of the interbrain connected with the stalk of the hypophysis cerebri.
- BULBUS OLFACTORIUS**. A protuberance connected with the telencephalon and representing one of the parts of the primordial portion of the rhinencephalon.
- CALAMUS SCRIPTORIUS**. The lowest angle in the floor of the fourth ventricle of the brain.
- CALCAR AVIS**. A projection in the wall of the occipital horn of the lateral ventricle produced by the calcarine fissure.
- CANAL, CENTRAL**. A small tubular canal found in the spinal cord during fetal life, sometimes persisting into adult life.
- CANAL, FALLOPIAN**. The osseous and membranous tube through which the facial nerve passes in the temporal bone.
- CANAL, NEURAL**. The lumen of the embryonic neural tube.
- CANAL, SEMICIRCULAR OR DUCTUS SEMICIRCULARIS**. The tubular lumen connected with the vestibular apparatus of the internal ear.
- CANAL, SUPRA-OPTIC**. A minute canal situated above the optic chiasm extending for a short distance above the optic nerve and connected with the third ventricle.
- CANALS, HOLMGREN-GOLGI**. A system of canalicular channels in the cytoplasm of nerve cells, also occurring in other cells of the body.

- CANALIS REUNIENS. A short canal within the internal ear uniting the saccule with the cochlea.
- CAPSULE, EXTERNAL. A narrow band of nerve fibers between the lenticular nucleus and claustrum.
- CAPSULE, INTERNAL. A massive band of nerve fibers passing in part through the corpus striatum and in part between the lenticular nucleus and optic thalamus. It contains the projection system of fibers connected with the interbrain and represents the gateway of nerve impulses passing to and from the cerebral cortex.
- CARNIVORES. Meat-eating mammals.
- CELL, ACIDOPHILIC. A cell having an affinity for acid stains.
- CELL, BASOPHILIC. A cell having an affinity for basic stains.
- CELL, BETZ. Giant pyramidal cell of the motor cortex.
- CELL, GOLGI TYPE I. A nerve cell whose axone passes out of the gray matter.
- CELL, GOLGI TYPE II. A nerve cell whose axone does not pass out of the gray matter.
- CELLS OF MARTINOTTI. Cells of the cerebral cortex whose axones ascend to the plexiform layer.
- CELLS, PURKINJE. The large motor cells of the cerebellar cortex.
- CENTROSOME. A small spherical body found sometimes in the nucleus, more commonly in the cytoplasm near the nucleus. Important in cell division.
- CENTRUM OVALE. The central core of medullary substance in the cerebral hemisphere.
- CEPHALOGYRIC MOVEMENT. Movement necessary to turn the head to right or left, upward or downward.
- CEREBELLUM (Little Brain). A suprasegmental portion of the central nervous system developed in connection with the metencephalon.
- CERVIX OF AXONE. The constricted part of the axone before the myelin sheath is added to the axis cylinder.
- CETACEA. The order of mammals comprising whales and porpoises.
- CHIASM, OPTIC. The decussation of the visual pathway situated in the floor of the interbrain.
- CHOREA. A form of hyperkinesis characterized by sudden irregular twitching of the limbs and other parts of the body.
- CHOREO-ATHETOSIS. A form of hyperkinesis characterized by choreic and athetoid movements.
- CHROMATIN. The principal element of the nucleus of cells.
- CHROMATOLYSIS. A pathological process in cells resulting in the solution and disappearance of the chromophilic substance.
- CINGULUM. A fasciculus of association fibers in the telencephalon connected with the gyrus cinguli.
- CISTERNA BASALIS. A portion of the subarachnoid space situated on the basal surface of the brain and forming the water-bed of the brain.
- CISTERNA MAGNA. Part of the subarachnoid space in relation with the cerebellum and medulla oblongata.
- CISTERNA PONTIS. Part of the subarachnoid space in relation with the pons Varolii.
- CLAUSTRUM. A narrow sheet of gray matter situated between the capsula extrema and the external capsule in the telencephalon.
- CLAVA. An eminence on the dorsal aspect of the medulla in relation with the caudal triangle of the fourth ventricle.
- CLIVUS. One of the superior vermal lobules of the cerebellum.

- CLONUS.** A type of hyper-reflexia characterized by oscillation of the foot, wrist, or leg.
- COCHLEA.** The auditory portion of the internal ear.
- COLUMN, DORSAL GRAY.** A column of gray matter represented by the dorsal horn on cross section.
- COLUMN, LATERAL GRAY.** A column of gray matter represented by the lateral horn on cross section.
- COLUMN, LATERAL SOMATIC MOTOR CELL.** Motor cell column in the lateral portion of the ventral gray column.
- COLUMN, LATERAL SPLANCHNIC MOTOR CELL.** Main portion of the lateral gray column.
- COLUMN, MESIAL SOMATIC MOTOR CELL.** Mesial portion of the ventral gray column.
- COLUMN, POSTERIOR VESICULAR, OF CLARKE.** Baso-mesial cell column.
- COLUMN, VENTRAL GRAY.** A column of gray matter represented by the ventral horn on cross section.
- COLUMN, VENTRAL SOMATIC MOTOR.** Ventral portion of the ventral gray column.
- COMMISSURE.** A band of fibers connecting corresponding parts of the central nervous system across the median line.
- COMPONENT.** A collection of neurones forming a functional system and conducting the afferent and efferent impulses in the two major mechanisms of the organism.
- COMPONENT, SOMATIC MOTOR.** The functional system serving to conduct impulses to the somatic effectors of the body.
- COMPONENT, SOMATIC SENSORY.** The functional system serving to conduct impulses received from the somatic receptors.
- COMPONENT, SPLANCHNIC MOTOR.** The functional system which serves to conduct impulses to the splanchnic effectors.
- COMPONENT, SPLANCHNIC SENSORY.** The functional system serving to conduct impulses received from the splanchnic receptors.
- CONTROL, ASSOCIATIVE AUTOMATIC.** The nerve impulses arising in the corpus striatum acting upon the final common pathway and thus upon the muscles.
- CONTROL, IDIODYNAMIC.** The impulses delivered from the ventral gray column cells and the motor nuclei of the brain stem which maintain the muscles in their normal trophic condition.
- CONTROL, REFLEX.** Those impulses transmitted to the muscles by one of the reflex arcs by means of which reflex action is maintained.
- CONTROL, SYNERGIC.** The impulses transmitted to the final common pathway from the cerebellum in order to regulate muscular activity of the synergic units of the body.
- CONTROL, TONIC.** The impulses transmitted to the final common pathway by way of the reflex arc to maintain the proper state of myotonus (muscle tone).
- CONTROL, VESTIBULO-EQUILIBRATORY.** Impulses transmitted from the receptors of the semicircular canals, saccule and utricle to the final common pathway in order to maintain body equilibrium.
- CONUS MEDULLARIS.** The caudal extremity of the spinal cord.
- CONVOLUTION.** An irregular elevated prominence on the surface of the cerebral hemisphere limited or bounded by two sulci.
- CORNU AMMONIS.** A submerged gyrus forming the larger part of the archipallium or olfactory cerebral cortex.

- CORONA RADIATA.** A series of bundles of projection fibers which radiate from the internal capsule toward the surface of the hemisphere.
- CORPORA MAMMILLARIA.** See mammillary body.
- CORPORA QUADRIGEMINA.** The dorsal part of the mesencephalon containing the superior and inferior colliculi.
- CORPUS CALLOSUM.** A large band of commissural fibers connecting the cerebral hemispheres.
- CORPUS LUYSI OR CORPUS HYPOTHALAMICUM.** A collection of gray matter situated in the subthalamus.
- CORPUS STRIATUM.** A sub-cortical collection of gray matter situated in each hemisphere of the telencephalon.
- CORPUSCLE OF DOGIEL.** A proprioceptive receptor.
- CORPUSCLE OF GOLGI-MAZZONI.** A proprioceptive receptor.
- CORPUSCLE OF GRANDRY-MERKEL.** An exteroceptive receptor.
- CORPUSCLE OF KRAUSE.** An exteroceptive receptor.
- CORPUSCLE OF MEISSNER.** A proprioceptive receptor.
- CORPUSCLE OF PACINI.** A proprioceptive receptor.
- CORPUSCLE OF TIMOFEEV.** A proprioceptive receptor.
- CORRELATION.** The neural combinations of impulses in specialized centers which usually result in adaptive motor reactions.
- CORTEX.** The outer gray layer sometimes called the mantle of the suprasegmental portions of the brain including the cerebellum, the tectum mesencephali and the cerebral hemispheres.
- CREST, ACOUSTICO-FACIAL.** The embryonic fundament in which the ganglia of the seventh and eighth nerves develop (geniculate, spiral and ganglion of Scarpa).
- CREST, NEURAL.** The embryonic fundament in which the dorsal root ganglia develop.
- CREST, TRIGEMINAL.** The embryonic fundament from which the Gasserian ganglion develops.
- CRUS.** A peduncle or massive collection of nerve fibers connecting different parts of the brain.
- CUL-DE-SAC, DURAL.** A sac situated in the caudal portion of the vertebral canal.
- CULMEN.** One of the lobules of the superior vermal portion of the cerebellum.
- CUNEUS.** An eminence on the dorsal aspect of the medulla lateral to the clava.
- CYCLOSTOME.** The lowest form of fish represented by petromyzon or lamprey.
- CYLINDER, AXIS.** The axone of a nerve cell.
- CYTOPLASM.** The protoplasmic substance of the cell body.
- DECUSSATION.** Crossing of the median line of the central nervous system of fibers in the course of some pathway, as for example the pyramidal decussation or the decussation of the mesial fillet. Such crossings effect a contralateral connection between one side of the body and the opposite side of the brain.
- DECUSSATION OF FOREL.** The crossing in the rubro-spinal tract in the midbrain. It is also called the ventral tegmental decussation.
- DECUSSATION OF MEYNERT.** Also known as the dorsal tegmental decussation, situated in the midbrain.
- DECUSSATION OF THE FILLET, LATERAL.** Decussation in the pons.
- DECUSSATION OF THE FILLET, MESIAL.** Decussation in the medulla.
- DECUSSATION, PYRAMIDAL.** Decussation in the medulla oblongata.
- DENDRITE.** One of the protoplasmic processes of the nerve cell.

- DERMATOME.** A cutaneous segment of the body.
- DERMIS.** The sub-epithelial portion of the skin.
- DIAPHRAGMA SELLÆ.** The bony fossa which lodges the pituitary body.
- DIENCEPHALON.** The interbrain comprising the thalamus, epithalamus, subthalamus, metathalamus and hypothalamus.
- DIPLOPIA.** Double vision; seeing double with both eyes open.
- DISC OF MERKEL.** An exteroceptive receptor.
- DORSUM SELLÆ.** The osseous caudal boundary of the diaphragma sellæ.
- DUCT, NEUROBUCCAL.** An ancestral connection between the mouth cavity and the ventricular chambers of the brain.
- DUCTUS ENDOLYMPHATICUS.** In mammals a vestige of an important duct connected with the internal ear.
- DYSARTHRIA.** Disturbed articulation usually due to paralysis of the muscles of articulation.
- DYSESTHESIA.** A subjective disturbance of somatic sensibility, such as tingling, numbness, sensations of burning, etc.
- DYSMETRIA.** Improper measuring of distance in muscular acts. A symptom of cerebellar disease.
- DYSPHAGIA.** Difficulty in swallowing due generally to paralysis of the muscles of deglutition.
- ECTODERM.** The outermost of the three embryonic layers. From it the nervous system together with the skin and its appendages takes origin.
- EDENTATA.** An order of mammals without median cutting teeth, including anteaters, sloths and armadillos.
- EFFECTOR.** The end-organ capable of distributing impulses which activate contraction in muscle or secretion in glands.
- EFFERENT.** Conducting from some part of the central nervous system toward the periphery.
- EMINENCE, OLIVARY.** A protuberance on the ventro-lateral aspect of the medulla oblongata indicating the position of the inferior olivary nucleus.
- EMINENCE, POSTCHIASMATIC.** A protuberance on the floor of the third ventricle immediately caudal to the optic chiasm.
- EMINENCE, POSTINFUNDIBULAR.** A small protrusion on the floor of the interbrain caudal to the tuber cinereum.
- EMINENTIA ABDUCENTIS.** An elevation on the floor of the fourth ventricle indicating the position of the nucleus of the sixth nerve and the genu of the facial nerve.
- EMINENTIA ACOUSTICA.** An eminence on the lateral aspect of the medulla oblongata indicating the position of the acoustic nucleus.
- EMINENTIA HYPOGLOSSI.** An elevation in the caudal triangle of the floor of the fourth ventricle indicating the position of the hypoglossal nucleus.
- EMINENTIA RESTIFORMIS.** An enlargement on the dorso-lateral aspect of the medulla indicating the position of the inferior cerebellar peduncle.
- EMINENTIA TERES.** The median longitudinal ridge on the floor of the fourth ventricle.
- EMINENTIA TRIGEMINI.** A small elevation on the lateral surface of the medulla oblongata indicating the position of the descending root of the fifth nerve.
- ENCEPHALOMERE.** One of the segmental divisions of the brain, so-called by McClure in contradistinction to the myelomere or spinal segment.

- ENDOCRINE.** Pertaining to the glands of internal secretion.
- ENDOLYMPH.** The fluid contained in the membranous internal ear.
- END-ORGAN, MUSCULO-TENDINOUS OF GOLGI.** An end-organ in the muscle.
- END-ORGANS.** The specialized structures which act as receptors of peripheral stimuli or as effectors for distribution of activating impulses.
- ENOPHTHALMOS.** A condition in which the eyeball is retracted and appears to be sunken in the orbit.
- ENTODERM.** The innermost of the three embryonic layers from which most of the viscera take origin.
- EPENDYMA.** The single layer of cuboidal ciliated epithelium lining the ventricles of the brain.
- EPICHOORDAL ENCEPHALON.** The portion of the brain situated dorsal to the notochord. This includes the spinal cord, myelencephalon, metencephalon and mesencephalon.
- EPIDERMIS.** The epithelial portion of the skin derived from the ectoderm.
- EPIPHYSIS.** A structure in the roof of the interbrain also known as the pineal gland or conarium.
- EPISTRIATUM.** A portion of the basal forebrain ganglion found in the lower vertebrates.
- EPITHALAMUS.** The portion of the interbrain derived from the roof-plate of the diencephalon.
- EUPHORIA.** An exaltation in the sense of well-being characteristic of paresis and seen in certain other mental diseases.
- EUPRAXIA.** The ability to perform skilled movements in a normal manner.
- EVAGINATION, OPTIC.** The embryonic diverticulum of the primitive forebrain from which the eye-cup takes origin. This structure gives rise to the retina.
- EXOPHTHALMOS.** An abnormal protrusion of the eyeball giving the eye undue prominence.
- EXTEROCEPTOR.** A receptor capable of receiving stimuli impinging upon the outer surface of the body.
- EYE-CUP.** The derivative of the optic evagination which gives rise to the retina.
- FALX.** The process of the dura between the cerebral hemispheres.
- FASCIA DENTATA.** One of the convolutions of the rhinencephalon (olfactory brain) also known as the gyrus dentatus.
- FASCICULUS.** A bundle of nerve fibers.
- FENESTRA OVALIS.** A foramen between the middle and internal ear.
- FENESTRA ROTUNDA.** A foramen between the middle and internal ear.
- FIELD OF FOREL.** A region in the subthalamus.
- FIELD, MYELINOGENETIC OF FLECHSIG.** A system of fibers in the neuraxis which receives myelin sheaths at a definite time of development.
- FIELD, TRIANGULAR OF WERNICKE.** An area adjacent to the optic thalamus, important because of the close proximity of the visual and somesthetic pathways at this point.
- FILA OLFACTORIA.** The afferent filaments composing the olfactory nerve which pass from the nasal mucous membrane through the cribriform plate to the olfactory bulb.
- FILA RADICULARIA.** The nerve filaments constituting the roots of the spinal and cranial nerves.

FILLET, also known as the lemniscus.

FILLET, BULBAR OR MESIAL. Serves for the conduction of impulses concerned in discriminative sensibility.

FILLET, PONTILE OR LATERAL. Serves for the conduction of impulses concerned in hearing.

FILLET, SPINAL. Serves for the conduction of impulses concerned in affective sensibility.

FILUM TERMINALE. The filamentous termination of the spinal cord extending from the conus terminalis to the end of the vertebral canal.

FIMBRIA. A fasciculus of nerve fibers connected with the gyrus hippocampus and joining with the body of the fornix.

FISSURE. A deep groove in the cerebral cortex between two adjacent convolutions. The fissures are of two orders, complete and incomplete, the complete fissure extending in such a way as to cause a protrusion in the wall of the ventricle.

FLEXURE. A bending of the neuraxis during development caused by unequal growth in its several parts. The regions in which these flexures occur are the cervical, pontile, mesencephalic and diencephalic.

FLOCCULUS. The lateral vestigial portion of the cerebellum situated in the cerebello-pontile angle.

FLOOR-PLATE. The ventral embryonic region of the neural tube which joins the lateral walls.

FLUID, CEREBROSPINAL. A clear fluid resembling lymph which fills the ventricles of the brain and the subarachnoid space surrounding the brain and spinal cord.

FOLD, NEURAL. The embryonic elevation of the ectoderm which forms the lateral wall of the neural tube.

FOLIUM. The cerebellar unit of structure forming the leaf-like subdivision of the cerebellum. Each lobe of the cerebellum is made up of a series of folia.

FORAMEN. An opening which permits passage of fluids or solid structures from one space to another.

FORCEPS ANTERIOR. A continuation forward of the interhemispherical association fibers into the frontal lobe from the genu of the corpus callosum.

FORCEPS POSTERIOR. The continuation backward of the interhemispherical association fibers into the occipital lobe from the splenium of the corpus callosum.

FORMATIO RETICULARIS. The reticular substance made up of gray and white matter found in the upper region of the cord and in the medulla.

FORNIX. A complex fasciculus of nerve fibers connecting the hippocampal formation with other parts of the brain; a conduction path connected with the olfactory portion of the brain.

FORNIX LONGUS OF FOREL. A fasciculus of fibers which perforate the corpus callosum and pass through the septum pellucidum.

FOVEA. Small depressions appearing in the floor of the fourth ventricle.

FOVEA CENTRALIS. Situated in the floor of the fourth ventricle between the two eminentiæ teretes.

FOVEA INFERIOR OR FOVEA VAGI. Marks the position of the dorsal nucleus of the vagus.

FOVEA SUPERIOR. Also known as the fovea trigemini, in the superior triangle of the fourth ventricle, marking the position of the trigeminus nucleus.

FRENULUM. A narrow band of gray matter extending in the sagittal plane from the cephalic extremity of the superior medullary velum to the intercollicular sulcus between the inferior corpora quadrigemina.

FUNCTION, ALLOMERIC. The function of the spinal cord and brain-stem dependent upon the integrative action of their several segments made possible through the white matter.

FUNCTION ISOMERIC. The individual functions of the several segments of the neuraxis.

GANGLIOBLAST. An embryonic ganglion cell.

GANGLIOCYTE. A ganglion cell.

GANGLION. A collection of nerve cells connected with a sensory root of a nerve or in the central nervous system.

GANGLION, DORSAL ROOT. A ganglion connected with the dorsal spinal root.

GANGLION, GASSERIAN. The dorsal root ganglion of the trigeminal nerve.

GANGLION, GENICULATE. The dorsal root ganglion of the seventh nerve.

GANOIDS. A sub-class of fish including the garpipes, sturgeons and bow-fins.

GEMMULE. A small enlargement on the protoplasmic processes of the nerve cell.

GENU. A knee or point of flexion.

GLIA. Neuroglia; the supporting tissue of the nervous system.

GLIOSIS. An increase of the neuroglia in the central nervous system.

GLOBUS PALLIDUS. The mesial portion of the lenticular nucleus; the paleostriatum.

GLOMERULUS. A conglomeration of blood vessels forming a spheroidal mass.

GLYCOSURIA. A condition characterized by sugar in the urine.

GRANULE, CHROMOPHILIC. A particle of pigment substance contained in the cytoplasm of the cell.

GROOVE, ACOUSTICO-FACIAL. The primitive fundament of the ganglion of the seventh and eighth nerves.

GROOVE, NEURAL. The groove formed by the embryonic neural folds.

GROOVE, OPTIC. The embryonic fundament of the optic vesicle.

GROOVE, TRIGEMINAL. The embryonic fundament of the Gasserian ganglion.

GRYOCHROME. A nerve cell in which the Nissl bodies are arranged in more or less concentric circles.

GYRUS. A convolution.

HEMIANOPSIA. Blindness in one half of the visual field.

HEMIPLEGIA. Paralysis of one half of the body.

HEMISPHERIUM. The hemispheres of the end-brain.

HERPES. An inflammatory eruption on the skin forming groups of small blisters.

HETEROMERIC CELLS. Cells whose axones make connections with the opposite side of the neuraxis, in contradistinction to the *Tautomeric Cells* which establish connection on the same side.

HETEROPHASIC. A partial form of aphasia in which the patient habitually says one thing when he means another.

HIATUS FALLOPII. An opening in the Fallopian canal for the transmission of the great petrosal nerve.

HIATUS NEURAL. Opening in the neural tube in the process of closure.

HILL, AXONE. An elevation in the nerve-cell from which the axone is given off.

HILUS. A small aperture permitting the entrance or exit of ducts, vessels or nerve fibers.

HIPPOCAMPUS. One of the two eminences on the floor of the lateral ventricle of the brain.

HYALOPASM. A part of the cytoplasm of cells.

HYDROCEPHALUS. Increased amount of cerebrospinal fluid accompanied by more or less marked dilatation of the cerebral ventricles.

- HYPERALGESIA.** A condition characterized by an increase in pain sensibility.
- HYPEREMIA.** A condition characterized by increase of blood in a part.
- HYPERESTHESIA.** A condition characterized by an increase of somatic sensibility.
- HYPERTHERMESTHESIA.** A condition characterized by increase of thermic sensibility.
- HYPERTONUS.** A condition characterized by increase of muscle tone.
- HYPOPHYSIS CEREBRI.** The portion of the brain lodged in the sella turcica and consisting of the infundibular process and pituitary gland.
- HYPOTHALAMUS.** The ventral portion of the diencephalon.
- HYPOTONUS.** A condition characterized by reduction in muscle tone.
- HYSTERIA.** An affection of the nervous system not due to any organic lesion, characterized by a mimosis of many other diseases. Hysterical paralysis and hysterical anesthesia may resemble in many respects the paralysis and loss of sensibility due to actual organic lesion.
- INDUSIUM GRISEUM.** The thin atrophic layer of gray substance on the upper surface of the corpus callosum.
- INFUNDIBULUM.** A portion of the hypothalamus.
- INNERVATION.** The imparting of nervous energy from the central nervous system to any part of the body.
- INSULA.** The portion of the hemispheres contained in the Sylvian fossa.
- INTEROCEPTOR.** A receptor connected with the viscera.
- INTIMA-PIA.** A combination of the pia mater and intima of blood vessels surrounding the arteries of the brain.
- INTRATHECAL PRESSURE.** The pressure of the cerebrospinal fluid within the sub-arachnoid.
- IPSI LATERAL.** On the same side, as for example, symptoms due to disease of a cerebellar hemisphere are on the same side as the lesion. [Etymologically *ipsilateral* is probably more accurate than *ipsolateral*, although the latter is used on good authority.]
- ISLAND OF REIL.** See *Insula*.
- ISTHMUS LIMBICUS.** The convolution connecting the gyrus cinguli and gyrus hippocampus.
- KARYOKINETIC PROCESS.** The division of cells by mitosis.
- KARYOPLASM.** The nucleus of the cell.
- KINETOPLASM.** The most highly contractile portion of the cytoplasm of cells.
- LACUNA.** A small space in a cell or tissue.
- LALOGNOSIS.** Understanding of speech.
- LAMINA.** A thin layer of tissue.
- LARYNGOPLEGIA.** Paralysis of the larynx.
- LATEROPULSION.** A tendency to run or fall to the side while walking.
- LEMUR ALBIFRONS.** A prosimian or limuroid primate mammal related to the monkeys.
- LEPTOMENINGITIS.** An inflammation involving the pia mater.
- LIMBUS CHORIOIDEUS.** The innermost arch of the limbic lobe.
- LIMBUS CORTICALIS.** The outermost arch of the limbic lobe.
- LIMBUS MEDULLARIS.** The middle arch of the limbic lobe.
- LINE OF BAILLARGER.** One of the medullary layers of the cerebral cortex.
- LINE OF GENNARI.** A characteristic medullary layer of the visual cortex.
- LINE OF KAES.** One of the medullary layers of the cortex.

LINGULA. The most cephalic vermal lobe of the cerebellum.

LIP, RHOMBIC. The lateral boundary of the rhombencephalon during embryonic life.

LOCUS CERULEUS. An area in the superior angle of the floor of the fourth ventricle.

LUMEN. A cavity of the tubular structure.

LUMEN, RESIDUAL. The residuum of the original lumen in the pituitary pouch.

LYMPH. The fluid contained in the lymphatic vessels.

LYMPHOCYTES. White blood cells.

MACULA. The spot of most acute vision in the retina.

MAMMAL, MACROSMATIC. A mammal with a highly developed sense of smell.

MARSUPIALS. Mammals having an external pouch in which the young are retained for some time after birth.

MATER, DURA. The outer covering of the nervous system.

MATER, PIA. The inner covering of the nervous system.

MECHANISM, SOMATIC. The organs and structures by means of which the somatic activities of the body are performed.

MECHANISM, SPLANCHNIC. The organs and structures by means of which the visceral activities of the body are performed.

MEDITULLIUM PROFUNDUM. A part of the tectum of the midbrain.

MEDULLA OBLONGATA. The caudalmost portion of the brain, also known as the myelencephalon.

MEMBRANE, SCHNEIDERIAN. The nasal mucous membrane.

MEMBRANA TECTORIA. An elastic membrane overlying the sulcus spiralis internus and the organ of Corti. The roof of the third ventricle.

MEMORY, KINESTHETIC. The memory of movements in the limbs and other parts of the body.

MENINGES. The coverings of the brain and spinal cord.

MENISCUS, TACTILE. One of the receptors of the skin.

MESENCEPHALON. The midbrain.

MESENCHYME. The loose embryonic connective tissue.

MESODERM. The middle of the three embryonic layers.

MESODERM, PARAXIAL. The mesoderm surrounding the neuraxis.

METABOLISM. The chemical changes going on in the tissues during life.

METAMERE. One of the series of homologous segments which form the body of a vertebrate or articulate animal.

METATHALAMUS. The part of the diencephalon consisting of the geniculate bodies.

METENCEPHALON. The hindbrain comprising the pons Varolii and cerebellum.

MICRON. One-millionth of a meter, or one-thousandth of a millimeter.

MICROPIA. A condition due to a visual disturbance in which all objects appear smaller than normal.

MIND-BLINDNESS. A disorder in which the patient is unable to recognize objects by the sense of sight although he is not blind; psychic blindness.

MIND-DEAFNESS. A disorder in which the patient is unable to recognize sounds by the sense of hearing although he is not deaf.

MITOSIS. A form of cellular division.

MONOTREMES. The lowest order of mammals.

MOTOFACIENT PHASE. The phase of muscular activity during which the muscle produces actual motion in some part, in contradistinction to the non-motofacient phase in which the muscle is contracting without producing motion.

MOTOR. The nervous impulses producing movement, i.e., contraction of muscle.

Often used in a larger sense as synonymous with efferent.

MUSCLE, SKELETAL. A somatic or striped voluntary muscle.

MUSCLE, SMOOTH. A non-striped, involuntary muscle.

MYASTHENIA. A condition characterized by great loss of muscular strength.

MYELENCEPHALON. The medulla oblongata.

MYELIN. The lipoid substance forming a sheath of the nerve and fibers.

MYELOMERE. One of the primitive segments of the spinal cord.

MYOSIS. A condition characterized by an abnormal contraction of the pupil;
also miosis.

MYOTOME. The portion of a somite from which a skeletal muscle is derived.

MYOTONUS. A condition in which the muscles are maintained in the state of tone
best adapted to their activities.

NECROSIS. A degenerative process resulting in the death of tissue.

NEOPALLIUM. That portion of the cerebral cortex which has been most recently
acquired during the process of evolution.

NEOPLASM. A new growth or tumor.

NEOTHALAMUS. The portion of the thalamus most recently acquired in the
process of evolution.

NERVOUS SYSTEM, CENTRAL. The portion of the nervous system contained within
the vertebral canal and skull.

NERVOUS SYSTEM, PERIPHERAL. The spinal and cranial nerves.

NERVOUS SYSTEM, VEGETATIVE. The sympathetic nervous system.

NET, ACHROMATIC. The network in the cell which does not stain with staining
reagents.

NETWORK, CHROMATIN. The network in the nucleus of the cell which stains with
staining reagents.

NETWORK, NEUROFIBRILLAR. The reticulum formed by the neurofibrils of the
nerve cell.

NEURASTHENIA. A condition characterized by loss of nerve strength.

NEURAXIS. The central nervous system.

NEURILEMMA. One of the coverings of a peripheral nerve.

NEUROBLAST. An embryonic nerve cell.

NEUROCYTE. A nerve cell.

NEUROFIBRIL. One of the fibrils contained in a nerve cell and its processes.

NEUROFIBROMA. A neoplasm characterized by the presence in it of neural and
fibrous elements.

NEUROGLIA. The supporting tissue of the central nervous system.

NEUROMERE. One of the segments of the nervous system.

NEURONE. The unit of structure of the nervous system comprising the nerve-cell
and its processes.

NEUROPORE. The mesial aperture in the prosencephalon prior to complete closure
of the neural tube.

NEUROSIS. A functional disorder in which the patient presents symptoms referable
to the nervous system.

NODES OF RANVIER. Characteristic features in the peripheral nerves.

NORMA. One of the planes or surfaces of the brain.

NOTOCHORD. The central axial structure of the embryo.

NUCLEUS. A collection of nerve-cells in the central nervous system.

NYSTAGMUS. Oscillation of the eyeballs, usually a pathological sign of disease in the cerebellum or vestibular mechanism.

OBEX. A small area of gray matter situated at the inferior angle in the roof of the fourth ventricle.

OCULOGYRIC MECHANISM. The combination of nerve centers concerned in movements of the eyes.

OLIVE, INFERIOR. A large nucleus situated in the medulla.

ONTOGENESIS. The development of the individual.

OPERCULUM. A lid; a structure overhanging a subjacent area.

OTOCYST. The embryonic structure from which the internal ear takes origin.

PACHYMENINGITIS. Inflammation of the dura mater.

PALATOPLEGIA. Paralysis of the palate.

PALEOTHALAMUS. The primordial portion of the thalamus.

PALLIUM. The gray and white matter forming the cortex of the endbrain.

PALSY. Paralysis.

PAPILLA. A small elevation of the skin or mucous membrane.

PAPILLEDEMA. An edema causing swelling of the optic disc.

PARAFLOCCULUS. A small portion of the cerebellum adjacent to the flocculus.

PARALYSIS AGITANS. Parkinson's disease, also known as "shaking palsy."

PARAPHASIA. A pathological disorder in which the patient shows marked disturbance in his speech.

PARAPHYSIS. One of the derivatives of the roof-plate of the endbrain.

PARAPLEGIA. Paralysis affecting both legs.

PARESIS. A loss of muscular power less profound than a paralysis.

PARESTHESIA. Perversion of somesthetic sensibility.

PAROLIVA. An accessory portion of the inferior olivary nucleus.

PATH OR PATHWAY. See tract.

PATHWAY, FINAL COMMON. The nerve cells and their processes by means of which impulses reach the effectors in the muscles and glands.

PEDUNCLE. A collection of fibers by means of which connection is established between different parts of the nervous system.

PERICHROME. A nerve-cell in which the Nissl bodies are arranged around the nucleus.

PERIMYSIUM. A connective tissue sheath about muscle fibers.

PERIOSTEUM. A specialized membranous sheath covering bones.

PES CAVUS. A pathological condition of the foot manifested by an excessively high arch at the instep.

PES LEMNISC. A bundle of aberrant pyramidal fibers associated with the mesial fillet.

PETROSA. The petrosal portion of the temporal bone.

PILLARS OF THE FORNIX. The compact bundles of fibers which proceed from the body of the fornix to the corpora mammillaria.

PINEAL BODY. The epiphysis or conarium; a gland developing in the roof of the third ventricle.

PITUITARY BODY. The glandular portion of the hypophysis cerebri.

PLACODE. The specialized area on the surface ectoderm giving rise to end-organs connected with the nervous system.

PLATE, ALAR. The portion of the neural tube dorsal to the sulcus limitans; it is sensory in character.

- PLATE, BASAL.** The portion of the neural tube ventral to the sulcus limitans; it is motor in character.
- PLATE, CUTIS.** The portion of the somite in which the dermatome arises.
- PLATE, NEURAL.** The specialized area of the primitive ectoderm from which the nervous system takes origin.
- PLEXUS.** A network formed by the interlacing of nerve fibers.
- POCKET, ORAL, OF RATHKE.** The embryonic fundament which gives rise to the pituitary gland.
- POLARITY, DYNAMIC.** Specialization of the nerve cell with reference to the flow of impulses.
- PONS VAROLII.** The ventral portion of the hindbrain in mammals.
- PRECUNEUS.** One of the lobes of the cerebral hemisphere seen upon the mesial surface of the brain.
- PRIMATES.** An order of mammals including man and monkeys.
- PROBOSCIDA.** An order of mammals with a proboscideous snout, as the elephants.
- PROCESS, INFUNDIBULAR.** The neural portion of the hypophysis cerebri.
- PROCHORDAL ENCEPHALON.** The portion of the brain situated in front of the notochord.
- PROPRIOCEPTOR.** A receptor situated in the muscles or deep tissues. This term also includes the receptors in the semicircular portion of the internal ear; this usage, however, is open to question.
- PROSENCEPHALON.** The most cephalic of the three primitive vesicles of the brain.
- PROTOPLASM.** The substance contained within the cell.
- PSYCHOSIS.** A disturbance characterized by mental aberration.
- PTOSIS.** The falling of an organ or part below its normal position; as visceroptosis, the falling of the internal organs; blepharoptosis, the drooping of the upper eyelid.
- PULVINAR.** A portion of the interbrain connected with the sense of sight.
- PUTAMEN.** A portion of the corpus striatum.
- PYRAMID.** A protrusion upon the ventral surface of the medulla oblongata.
- PYRAMIS.** A portion of the vermis of the cerebellum.
- PYROMANIA.** An abnormal passion for incendiarism.
- RAMI COMMUNICANTES.** Collections of nerve fibers connecting the spinal cord with the sympathetic ganglia.
- RAPHÉ.** A seam-like appearance in many organs at the median line, as the raphé of the tongue.
- RECEPTOR.** The end-organ for the receipt of sensory stimuli.
- RECESSUS FASTIGII.** A recess in the roof of the fourth ventricle.
- RECESSUS PREOPTICUS.** The recess in front of the optic chiasm.
- REFLEX ACTION OR MOVEMENT.** An action produced by the transmission of an afferent impulse to a nerve center and reflected thence as an efferent impulse to an effector independent of volition.
- RETICULUM.** A network.
- RHINENCEPHALON.** The olfactory portion of the endbrain.
- RHOMBENCEPHALON.** That part of the encephalon formed by the medulla, pons and cerebellum.
- RIGOR MORTIS.** The rigidity of the muscles after death.
- ROOF-PLATE.** The embryonic structure forming the dorsal limit of the neural canal.

ROSTRUM, OF THE CORPUS CALLOSUM. The beak-like extremity of the corpus callosum.

SAC, DURAL. The process of dura at the caudal extremity of the spinal cord.

SACCUS VASCULOSUS. A structure in the floor of the third ventricle seen in fish.

SACRUM. The caudal portion of the vertebral canal.

SCLEROSIS. The pathological process resulting in hardening.

SCLEROTOME. The portion of the somite which gives rise to the segmented bony structures of the vertebral column.

SCOLIOSIS. Lateral curvature of the spine.

SEGMENT, BRANCHIAL. One of the gill segments.

SELACHIANS. A class of vertebrates including sharks and rays.

SELLA TURCICA. The cavity in the skull which lodges the hypophysis cerebri.

SENSE, MUSCLE. Somesthetic sensibility derived from muscle receptors.

SENSIBILITY, SOMESTHETIC. Sensory consciousness dependent upon somatic sensory receptors.

SENSIBILITY, SPLANCHNESTHETIC. Consciousness dependent upon splanchnic receptors.

SENSORY. Nervous impulses resulting in conscious sensation. Often used in a larger sense as synonymous with afferent.

SEPTULA. A small septum.

SEPTUM. A division or dividing plane usually of connective tissue.

SOMA. The body of a nerve-cell or neurone.

SOMESTHESIA. Body-feeling sensibility.

SOMITE. One of the metameric segments from which the body is derived.

SPACE, EPIDURAL. The space between the dura and the bone specially prominent in the spinal region.

SPACE, SUBARACHNOID. The space containing the cerebrospinal fluid.

SPASM, TONOCLONIC. A convulsive twitching of the muscle.

SPASTICITY. Pronounced hypertonus of the muscles.

SPHINCTER IRIDIS. The muscle producing contraction of the iris.

SPIRAL, TENDON. The receptor connected with a tendon.

SPLENIUM. The caudal portion of the corpus callosum.

SPONGIOBLAST. A primitive cell in the nervous system which gives rise to neuroglia.

STALK, INFUNDIBULAR. The slender constricted structure which attaches the infundibular process to the bulbus infundibuli in primates.

STALK, OPTIC. The embryonic structure which connects the optic vesicle with the diencephalon in the embryo.

STEREOGNOSIS. The perception and understanding of the form of objects by the unaided sense of touch.

STICHOCHROME. A nerve-cell in which the Nissl bodies are arranged in rows.

STRABISMUS. A pathological condition in which one or both eyes are more or less permanently turned inward or outward.

STRİÆ ACOUSTICÆ. The nerve fibers connected with the auditory pathway which cross the floor of the fourth ventricle.

STRİÆ MEDULLARES. Narrow fasciculi of nerve fibers in various portions of the central nervous system in close relation with the surface.

SUBICULUM. A portion of the gyrus hippocampus.

SUBSTANCE, CHROMOPHILIC. The constituents in the cell having affinity for stains.

- SUBSTANCE, MEDULLARY.** The white matter of the central nervous system which consists of axones and their myelin sheaths.
- SUBSTANTIA GELATINOSA.** The gray matter surrounding the caput of the dorsal gray column.
- SUBSTANTIA INNOMINATA.** The nerve tissue situated immediately caudal to the anterior perforated space.
- SENSORY.** Nervous impulses resulting in conscious sensation. Often used in a larger sense as synonymous with afferent.
- SUBSTANTIA NIGRA.** The large mass of gray matter lying between the tegmentum and basis of the midbrain.
- SUBTHALAMUS.** The primordial portion of the interbrain situated immediately ventral to the thalamus.
- SULCUS.** A groove or furrow.
- SYMPATHICOBLAST.** An embryonic nerve cell which gives rise to a sympathetic cell.
- SYNAPSE.** The process by which the end brush of an axone establishes contact with the dendrites of another cell.
- SYNCYTIUM.** A tissue consisting of cells without cellular boundaries.
- SYNERGIA.** The chief function of the cerebellum which results in the coordinated action of the muscles of the body.
- SYRINGOMYELIA.** A pathological condition of the nervous system caused by the formation of a tubular cyst in or near the gray commissure of the spinal cord.
- TABES DORSALIS.** A disease of the nervous system due to syphilis and causing locomotor ataxia.
- TASTE-BUD.** The end-organ consisting of receptors for the sense of taste.
- TAUTOMERIC.** See *Heteromeric*.
- TECTUM MESENCEPHALI.** The suprasegmental part of the midbrain.
- TEGMENTUM.** The dorsal part of the medulla, pons Varolii and midbrain.
- TELA CHORIOIDEA.** The thin non-nervous part of the roof or lateral walls of the brain vesicles forming the chorioid glands.
- TELENCEPHALIZATION.** The evolutionary process as a result of which supervision of more complex neural reactions has been transferred to the endbrain.
- TELENCEPHALON.** The endbrain.
- TELEOSTS.** An order of fish known as the bony fish.
- TENTORIUM CEREBELLI.** The process of dura mater separating the cerebral hemispheres from the cerebellum.
- TETRAPLEGIA.** Paralysis of all four extremities.
- THALAMUS.** The largest portion of the interbrain.
- THROMBOSIS.** The formation of a clot during life in one of the blood vessels or the heart.
- TITUBATION.** A staggering gait.
- TONSIL, OF THE CEREBELLUM.** A portion of the lateral lobe of the cerebellum.
- TORCULAR HEROPHILI.** The point of confluence of the lateral and superior longitudinal sinuses in the skull.
- TOXEMIA.** A toxic condition of the blood.
- TRACT.** A collection of homodynamous fibers arising from a nucleus and coming in contact with the nucleus of another tract. Several superimposed tracts constitute a pathway which serves for the conduction of a specific type of nerve impulse.

TRAUMA. A wound or injury of any kind.

TREMOR, FIBRILLARY. A fine, rhythmic trembling.

TRIGONUM HABENULÆ. Part of the paleothalamus.

TRIGONUM LEMNISC. An area on the lateral surface of the isthmus between the hindbrain and midbrain. It marks the position of the lateral fillet.

TUBER CINEREUM. A part of the hypothalamus in mammals.

TUBERCULOMA. A tumor due to the tubercle bacillus.

UNCUS. A part of the hippocampal formation.

UNGULATES. An order of mammals having hoofs.

UTRICLE. A part of the apparatus of the internal ear.

UVULA CEREBELLI. One of the lobes in the inferior vermis of the cerebellum.

VASOMOTOR SYSTEM. The portion of the nervous system controlling the blood vessels.

VEGETATIVE SYSTEM. Synonymous with the sympathetic system.

VELLUS OLIVÆ INFERIORIS. A narrow band of tangential fibers surrounding the inferior olive.

VELUM. A thin lamina of nerve tissue found at several points in the roof of the brain or extending into its cavities.

VENTRICLE. A more or less spacious chamber in the brain containing cerebro-spinal fluid.

VERMIS CEREBELLI. The central portion of the cerebellum.

VERTEBRATES. A division of the animal kingdom comprising all animals possessed of a vertebral column and including cyclostomes, selachians, teleosts, ganoids, dipnoians, amphibia, reptiles, birds and mammals.

VESTIBULE, OF THE EAR. The small elliptical cavity of the internal ear behind the cochlea and in front of the semicircular canals.

VIBRISSA. A short, stiff, coarse hair, as in the nostril of man and about the mouths of mammals. It has a high degree of sensitiveness.

VISCERA. The internal organs.

ZONA INCERTA. A small area in the subthalamus.

ZONE, ECTOPTIC. A region observed in the early development of the prosencephalon and first described by Schulte. From it arise the interbrain and endbrain.

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